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Improving efficiencies and modeling a cyclic Suspended Ion Exchange (SIX(c)) drinking water pre-treatment systems

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IMPROVING EFFICIENCIES AND MODELING A CYCLIC SUSPENDED ION EXCHANGE (SIX©) DRINKING WATER PRE-TREATMENT SYSTEM

BY

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THESIS

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Date

DEDICATION

This work is dedicated to my wife, for without her understanding and support, this project would never have been started or finished.

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I would like to thank PWN for the opportunity of allowing me to work with their new technologies and for giving me the learning opportunities that I would not have been able to get anywhere else.

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This research focused on three primary components of the Suspended Ion eXchange (SIX©) process developed by PWN Water Supply Company North Holland. The first step focused on the resin regeneration procedure. It was shown that the current system could be improved and that reducing the complexity of the system simplified the process and increased the regeneration efficiency. The second step focused on the resin tank contactor hydraulics. It was determined that for the sequential completely mixed reactor design at PWN, high flows with low mixing speed of the overhead paddle mixers led to the most efficient hydraulic regime. The third step focused on the spent resin regeneration solution reuse. It was shown that cyclic ion exchange was possible with SIX© and could be feasible achieved with using biological denitrification and nanofiltration only allowing the waste stream to be treated and then directly reused.

CHAPTER 1

INTRODUCTION

1.1 PWN Water Supply Company North-Holland

In 1920 PWN Water Supply Company North-Holland (PWN) was founded by the local provincial government to provide water to the region from the only local fresh water source, the dune area along the North Sea. In 1934 PWN was given charge over the dune area as well as the protection of the dune wildlife.

Due to increases in water demand over time (from population growth and increased industrialization), in 1952 the Water Transport Company Rijn-Kennemerland (WRK I&II) was established in cooperation with the Amsterdam Waterworks and in 1956 began to pump water from the river Rhine into the dune area near Castricum. This was to supplement the drinking water supply and to provide a barrier against sea water intrusion.

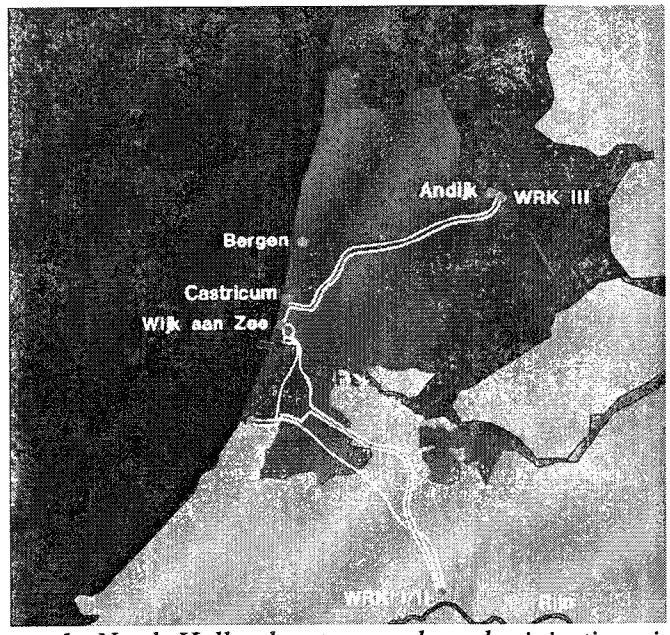

Figure 1– North-Holland water supply and reinjection piping

Then in 1968 to further combat the increasing drinking water demands, Water Treatment Plant (WTP) Andijk was built and began treating surface water directly from Lake IJssel to provide the region of West-Friesland with drinking water. In order to address concerns surrounding taste and odor issues the first of their kind pseudo moving bed granular activated carbon (GAC) filters were added to the treatment process. The GAC filters also proved to be a barrier against disinfection by-product formation from the chlorine addition.

After 40 years of operation WTP Andijk was still meeting all national Dutch drinking water regulations, but with increased awareness of organic micro pollutant contamination such as pesticides and the desire to create an improved barrier against pathogenic micro organisms such as protozoa, the first large scale application of ultraviolet light and hydrogen peroxide (UV/H_2O_2) in the world was installed in Andijk.

PWN is still thinking towards the future and continues to make efforts to create a more sustainable process that can have universal treatment while limiting waste streams.

To do this PWN is developing an ion exchange process followed by ceramic micro filtration to replace traditional coagulation, flocculation, and rapid sand filtration (CSF) as pre-treatment for the UV/H_2O_2 system and GAC.

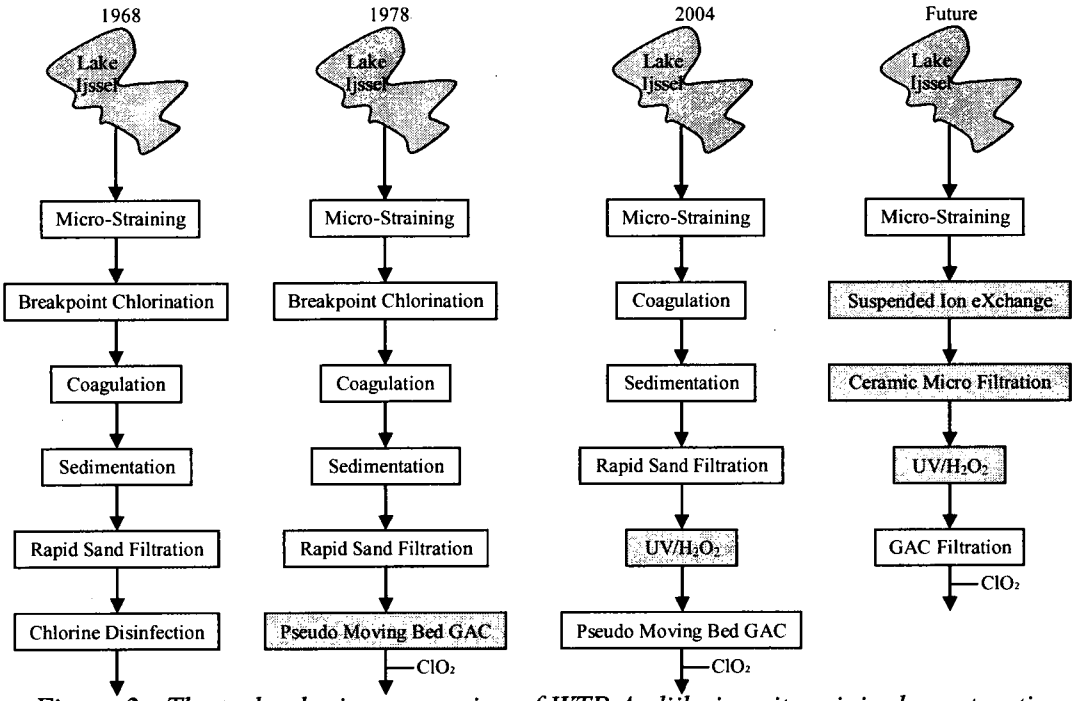

Figure 2 - The technologic progression of WTP Andijk since its original construction

Currently PWN treats approximately 12,000 m^3/hr (76.0 MGD) for its one and a half million customers. The treated water originates from the Lake IJssel and the River Rhine. Besides direct treatment at WTP Andijk, PWN uses the dune area for storage and a final polishing step for the pretreated Lake IJssel and River Rhine water (WRK I/II, III).

1.2 The New Water Treatment Scheme at PWN

The treatment based on ion exchange, membrane filtration and advanced oxidation as developed by PWN is proposed as a comprehensive barrier against many of the water

quality issues arising today such as pharmaceuticals, pesticides, and herbicides. It also has the ability to treat surface water creating minimal waste streams in an effort to be more sustainable.

The current process at PWN uses ferric chloride as a coagulant and due to the raw water characteristics requires high dosing levels (up to 25mg/L) resulting in large sludge volumes. PWN is trying to reduce this large sludge volume by using ion exchange resins to capture the dissolved compounds typically bound with the iron. The resins are able to be regenerated and reused, eliminating the sludge production.

The micro-filtration unit being proposed to replace traditional sand filtration is made of ceramics as opposed to polymer membranes. This ceramic construction allows for much more vigorous cleaning regimes to be implemented allowing this process to be applied more directly to surface water sources. Many of the more traditional pretreatment steps such as cartridge filtration or coagulation are not required.

PWN has already started to use an advanced oxidation process (AOP) combining UV light and hydrogen peroxide to generate the hydroxyl radical for organic contaminant control. The required high UV dose for AOP also provides superior disinfection.

1.2.1 Ion Exchange for the Treatment of Drinking Water

The purpose of ion exchange in this drinking water process is to remove negatively charged species from the feed water. PWN in particular is looking for natural organic matter (NOM) and nitrate removal, specifically the dissolved organic carbon (DOC) fraction. This is to reduce membrane fouling in order to make raw water micro-filtration possible. Ion exchange will also reduce the UV absorbance of the treated water

by removing DOC and ions such as nitrates or sulfates. DOC removal also enhances the UV/H_2O_2 process by reducing the hydroxyl radical scavenging.

The ion exchange unit uses resins to adsorb the detrimental substances and replaces them with inert ions such as sodium or chloride. The resin needs regular regeneration. The regeneration process is done by contacting the resin with a highly concentrated solution of salt, acids, or bases.

The regeneration step generates a waste stream comprised primarily of the rinse solution, but also contains the constituents removed from the resin (e.g. DOC and nitrates). For economic or environmental reasons the waste stream may need to be treated before it can be released or reused. For instance a used regeneration solution may not be discharged into the sea or into the local sewer because of its high salt content.

For PWN, it is currently purposed to clean the used regeneration stream. For their situation, this can be done with a biological treatment step to remove nitrates in combination with a nanofiltration unit to remove DOC. This would leave only the monovalent regenerant salt in the solution. PWN is developing the steps necessary to treat and concentrate this stream to reuse it in regenerating the ion exchange resin. This saves on disposal fees and chemical costs and also reduces the waste stream generated by the process.

1.2.2 Developing Ion Exchange at PWN for Primary Treatment

Traditional ion exchange units such as fixed bed contactors have complications that arise from treating raw surface waters. One issue is resin fouling or blinding where the resin gets covered in organic or particulate matter reducing absorption capacity.

Another issue is the clogging of the pores between the resins from the colloidal particles in the raw surface water decreasing production rate.

Because of these issues PWN looked into suspended ion exchange as an alternative. Putting the resin in suspension instead of a fixed bed eliminates the pore clogging issues. The current state of the art in continuous and suspended ion exchange processes applies the Magnetic Ion EXchange (MIEX®) resin. It has been developed by Orica Watercare, Water Corporation of Western Australia, and CSIRO Molecular Science. This process uses a specially engineered magnetic resin that settle out of suspension rapidly allowing for application in unique ways. The system uses a batch contact method and continuous partial regeneration of the resin to create a truly continuous ion exchange process. The AWWA ion exchange publication regards the batch contact method as inefficient (Wachinski, 2005). Because of this inefficiency and commercial reasons such as limited resin suppliers, PWN redesigned the process to fit their specific needs and developed SIX.

CHAPTER 2

RESEARCH DESCRIPTION

2.1 Introduction

The research being conducted will revolve around the further development and improved efficiencies of certain aspects of the SIX installation at PWN. Specifically the research will focus on the resin regeneration process with a look at the potential for regeneration solution reuse and the hydraulics of the contactors.

The SIX installation is an ion exchange system that uses vertical cylindrical contact chambers containing baffles and mixing paddles to help distribute flow and ensure proper mixing. The resin is injected into raw feed stream just before the first contact tank and it is removed directly after the second contact tank by a modified lamella plate settler.

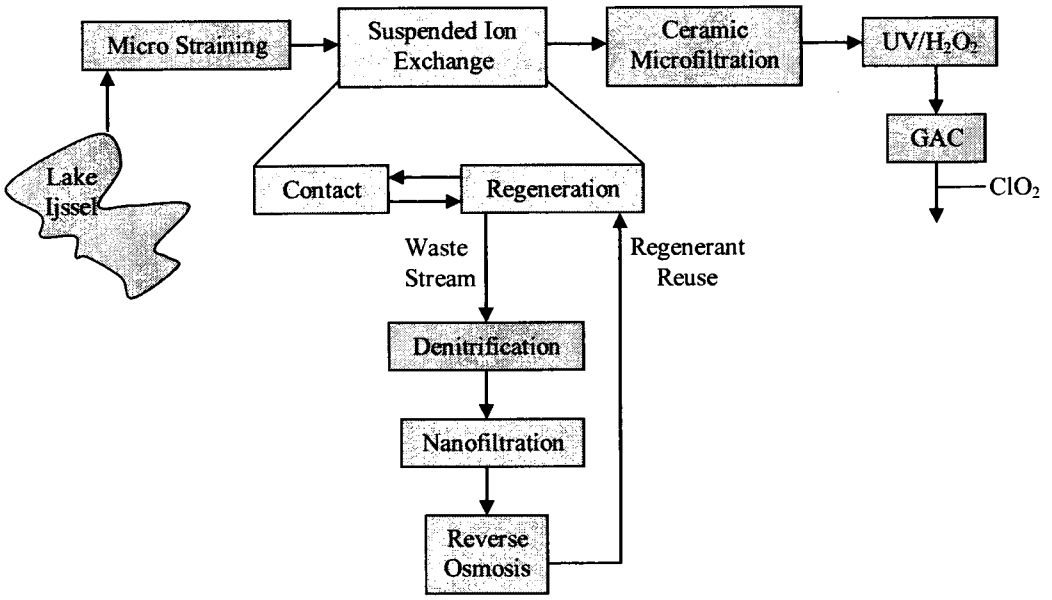

Figure 3 - Schematic of proposed water treatment scheme at PWN with research areas highlighted in yellow.

Once the resin is settled out of the feed stream, it is regenerated with highly concentrated salt solutions in the regeneration vessels. The regeneration process uses three salt solutions to renew the resin and is then followed by two rinsing cycles to wash away the excess salt. Once the regeneration is complete, the resin is dropped down into the fresh resin tanks to be re-injected into the feed stream.

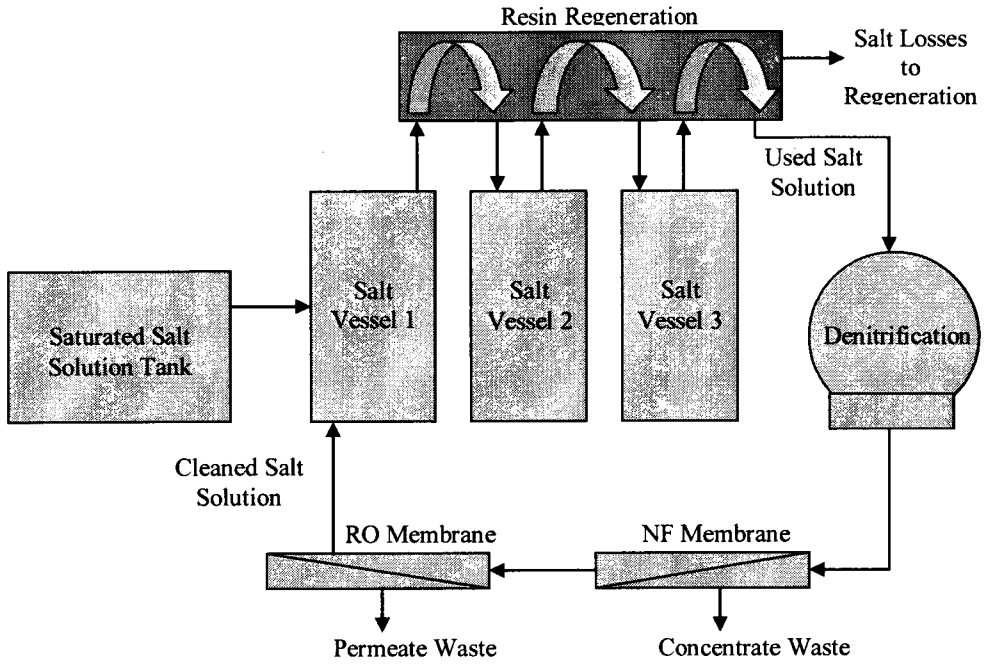

Figure 4 - The schematic of the current resin regeneration process with the proposed cleaning steps for the salt reuse.

The solution that comes from the resin regeneration process contains desorbed compounds and needs to be treated before it can be disposed of or reused. This treatment needs to separate the salt solution from the desorbed nutrients and organics coming from the regenerated ion exchange resin. The foreseen regeneration fluid treatment is biological denitrification, followed by nanofiltration (NF) and reverse osmosis (RO).

2.2 Problem Definition

The current regeneration process for the resin used in the SIX system works, but there is limited insight as to whether this system is at its most effective. Contrary to the adsorption models, accurate kinetic desorption models of the current resin have not been created yet. Therefore predictions and estimations of regeneration cannot be made.

To judge the performance of the ion exchange pilot, the hydraulic characteristics must be known to support results from pilot testing by knowing if there is short-circuiting

or dead zones. Also, even and consistent hydraulic flows ensure that all of the resin is evenly distributed in the system and has consistent and predictable contact times. The design of the current SIX pilot is new. There is limited experience at what operating conditions it is most hydraulically effective.

A highly concentrated solution of sodium chloride (one third of its saturation concentration) is needed to regenerate the anionic resin and to restore the resin to an efficiently functioning state. These high salt concentrations in the regeneration stream translate to high salt usage and consumption. In order to make the process more sustainable and reduce the chemical consumption and waste stream volumes, reuse of the used regeneration solution is ideal. The solution contains high levels of dissolved organic carbon (typically 300 to 400 mgC/L) and nitrate (approximately 300 mg/L as nitrate) as well as other ions such as sulfate. These levels need to be reduced while allowing the salt to stay in solution before it can be concentrated and used again in regeneration.

2.3 Objectives

The main objective of the resin studies is to accurately model the desorption characteristics and determine the most efficient regeneration process in the pilot. The focus will be on the most efficient regeneration regime and the simplest process to implement within the current physical restrictions of the pilot. The model generated will be verification on the pilot scale.

The second objective is to hydraulically characterize the new contactor vessels of the SIX system over a range of operating conditions, measuring removal efficiencies as well to see which gives the most consistent and maximized treatment.

The third objective is a feasibility study on treatment of the used regeneration stream for reuse. The focus will be on the application of nanofiltration and reverse osmosis after denitrification.

2.4 Research Tasks

From the objectives, the following research questions have been derived:

First Objective:

1. Model the current resin desorption characteristics with bench scale jar tests.
2. Use the model to predict the most efficient regeneration process by varying contact times and number of regeneration solutions used in the pilot.
3. Compare model results to pilot results and determine model accuracy within the physical limits of the pilot.

Second Objective:

4. Verify homogenous resin loading and optimal hydraulic operating conditions for the SIX pilot.
5. Determine if the best hydraulic conditions provide the best water treatment.

Third Objective:

6. Pilot test the concept of DOC retention and salt passage of the regeneration solution waste stream with nanofiltration.
7. Determine if it is feasible to operate a nanofiltration unit over multiple days with the regeneration waste stream without irreversible fouling.
8. Perform calculations to check salt retention and concentration with RO membranes to make the cleaned regeneration solution reusable.

2.5 Limitations and Boundary Conditions

The following are the limitations and boundary conditions on this research imposed by the physical and operational restrictions at the PWN pilot facility.

- The research will be done on the bench scale and on the pilot scale levels.
- The surface water source used is high in dissolved organic carbon (DOC) and nitrate (NO_3) making them the primary indicators of water quality for this research.
- In-house DOC values are based on an established relationship between UVT_{254nm} and DOC concentrations.
- All pilot research will be limited to the already constructed pilots.
- Tracer studies will be conducted with a dissolved tracer and not a particle tracer (which would more accurately predict the resin distribution).
- The SIX pilot is restricted to operate at flows between $20m^3/hr$ and $50m^3/hr$
- The SIX pilot is restricted to mixing speeds of between 20rpm and 45 rpm with its overhead paddle mixers.
- The research will be done using only the Lewatit® VPOC 1071 Anion Exchange Resin (the current resin used in the pilot).
- The regeneration optimization will be done within the physical and time restrictions of the current pilot design. This being the use of one to three salt solutions mixed with the resin for a total process time of 55 minutes.
- The regeneration fluid reuse research will be restricted to NF and RO membranes, not denitrification.
- The NF pilot is flushed with a mixture of drinking water and air.

CHAPTER 3

LITERATURE REVIEW

In the following chapter different processes and concepts will be explored to lay out the foundations needed to perform the intended research. This will be done through a review of literature on the specific technologies. This chapter with discuss the basics of ion exchange, ion exchange resins, ion exchange contactors and the usage of ion exchange in surface water treatment. It will also discuss the steps involved in creating a cyclic operating ion exchange such as biological denitrification, nanofiltration, and reverse osmosis.

3.1 Ion Exchange Resins

3.1.1 The State of the Art

Ion exchange is a term that describes the industrial process of ion exchange as well as the natural phenomenon that occurs each day in all living organisms. Commercial ion exchange processes are widely used in water treatment and are most commonly used for removing hardness from water, namely the cations calcium and magnesium (Wachinski, 2006). Ion exchange can occur for any ionic species though. The process is achieved when anions or cations in solution are exchanged for anions or cations attached to the ion exchange resin which has only one of these two types of ions mobile. The

anions and cations remain in electroneutrality and therefore remain stable and do not degrade or change during usage (Wachinski, 2006).

The object doing the exchanging in water treatment is often a resin and is typically used in bead form. These resins have the fixed anion or cation compounds with an oppositely charged mobile ion attached to them. The example in *Figure 5* is of a cation exchange resin meaning that the permanent bonding sites have a negative charge and the cations attached to that negatively charged site are the mobile compounds.

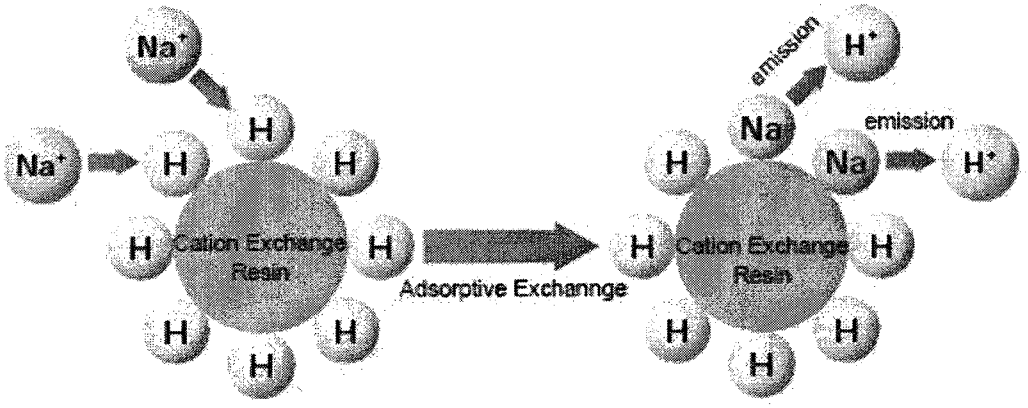

Figure 5 - Example of ion exchange occurring with a cation exchange resin.
Photo courtesy of: www.astom-corp.jp

Once the resin has most or all of its available bonding sites exchanged and taken up with the various ions that it has removed from the treatment stream, the resin is no longer viable and needs to be replaced or regenerated. Since total replacement is expensive and uses far too much resin, regeneration is the typical answer (Liu et al, 1996).

Equation 1 shows a typical ion exchange equation for an anionic resin and displays that it is a reversible reaction. One direction is more favorable than the other and in that way the exchange in the contactor will occur. It also means that if forced the other

direction with high enough concentrations, the equation will reverse and discharge the ions removed from the waste stream in exchange for the higher concentrated ion. This is the regeneration process (Wachinski, 2006).

$$R-N\bullet Cl+HNO_3 \longleftrightarrow R-N\bullet NO_3+HCl$$ *Equation 1*

Resins are typically regenerated with salts, acids, or bases depending on the specific resin and its characteristics. These substances are used because they are often available in large quantities and dissociate completely in water giving high concentrations needed (Liu et al., 1996). In *Equation 1* the resin could be recharged with either hydrochloric acid or another highly dissolvable compound with chlorine such as sodium chloride.

The desire at PWN is to remove NOM, specifically the DOC fraction that binds ups and fouls the surface of membrane treatment systems. Since DOC is a negatively charged compound (Shim et al., 2002), anion exchange resins can be used to remove it from the treatment stream.

The key water quality factors in this type of study are NOM and nitrate (Schippers et al., 2004). Both of these compounds are negatively charged in their dissolved ionic form meaning that anion exchange resins can be used to remove them from the treatment stream.

There are three primary kinds of anionic exchange resin, strongly basic (I & II) and weakly basic. Strongly basic anionic resins are composed of strong basic components that bind well with anionic compounds.

Type I strongly basic resins have trimethylammonium for their exchange group and binds very strongly with the ions it is removing. Because of this strong bond Type I

can remove and stay better bound to more ions than the other type, but is harder to regenerate and requires more regenerating solution (Wachinski, 2006).

Type II is still strongly basic but uses dimethylethanolammonium as the exchange group and while still strongly basic, is slightly weaker than Type I. Because of being weaker, Type II does not bind as strongly to the ions it is removing and has a higher chance of the ions detaching during treatment. The higher tendency for detachment makes Type II easier to regenerate (Wachinski, 2006).

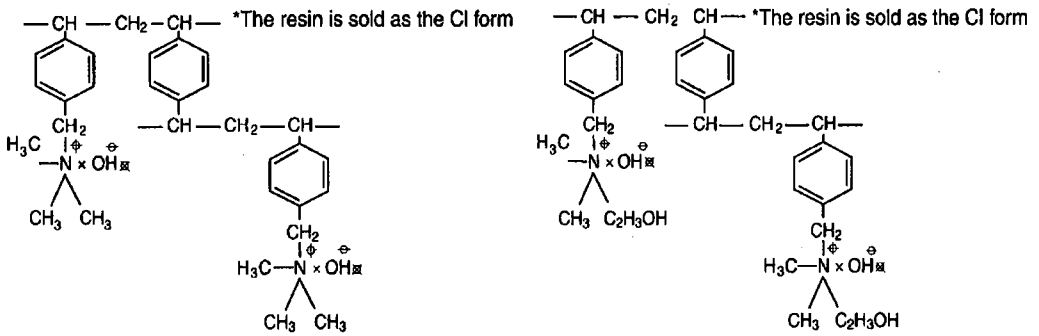

Figure 6 – Chemical structure of Type I (left) and Type II (right) strongly basic anion exchange resins (Wachinski, 2006).

Weak based anion exchangers were the first anion exchange resins developed and remove only the highly dissociated ions from solution such as nitrates or sulfates. The advantage to the weak based exchanger is that it holds nearly twice the capacity for exchange as the strongly basic forms and can be regenerated more readily with various compounds unsuitable for the strongly basic resins (Wachinski, 2006).

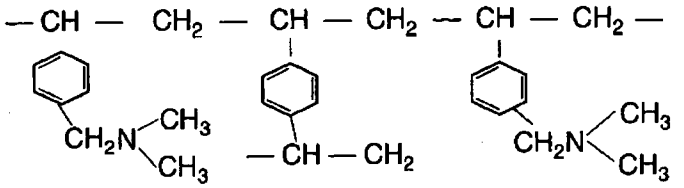

Figure 7 – Chemical structure of weakly basic anion exchange resins (Wachinski, 2006).

3.1.2 PWN Perspective on Ion Exchange Resins

Before the current research was conducted, there were experiments done at PWN to determine and characterize the best resin to use for the new ion exchange process (Koreman et al., 2009). *Figure 8* and *Figure 9* shows the specific anionic resins researched at PWN and their relative capacities for DOC removal for volume and over time. In this situation UVT_{254} increases are used as an inversely proportional surrogate for DOC removal increases. See section 4.2.7 for specifics on equating UVT_{254} to DOC concentration.

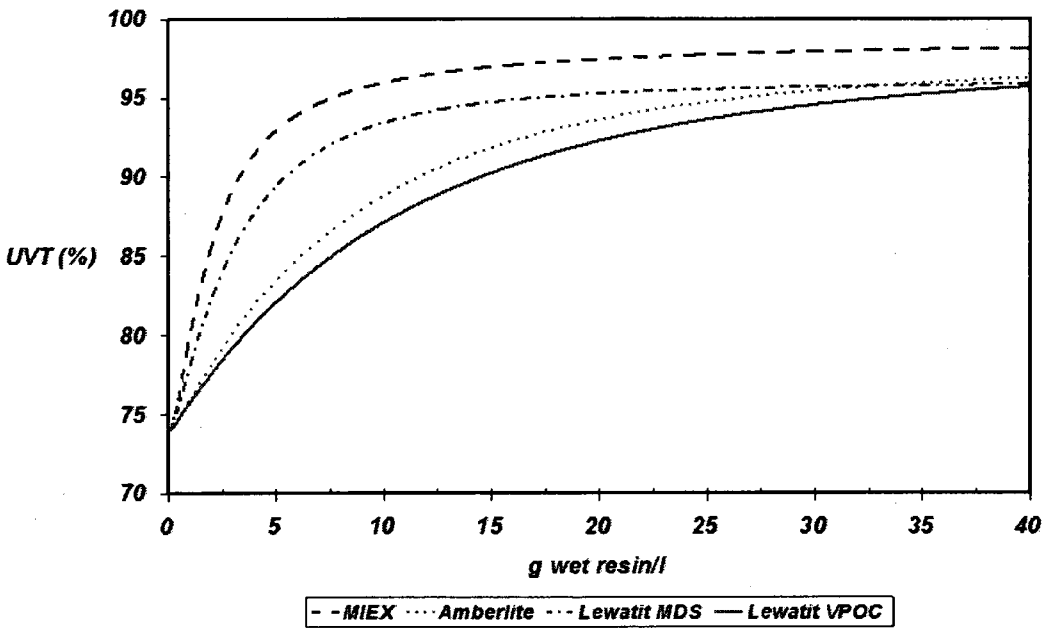

Figure 8 – Adsorption kinetics for the primary resins researched at PWN comparing volume of resin required to reach various treatment levels.

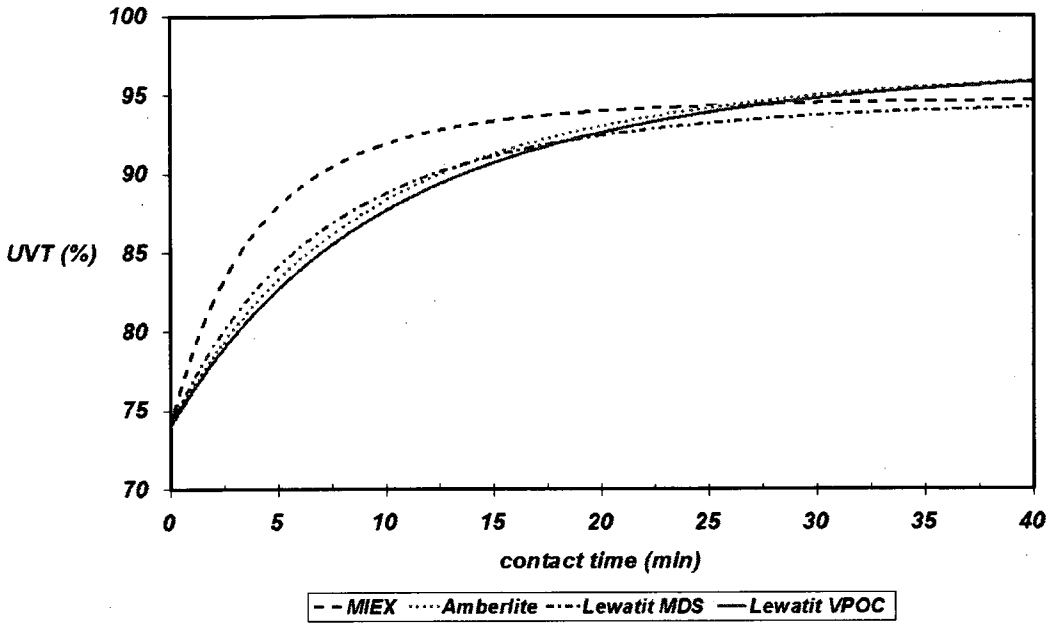

Figure 9 – Adsorption kinetics for primary resin research at PWN comparing contact time needed with various concentrations to reach various treatment levels.

Figure 8 and *Figure 9* show that the MIEX® resin improves the water UVT_{254} the fastest at the lowest concentrations. It also shows that the Amberlite resin improves UVT254 better at lower concentrations than either of the Lewatit® resins but at equalized concentrations the contact times needed are similar. One issue with the MIEX® resin that was found was its low affinity towards nitrate adsorption. *Figure 10* shows the influent and effluent nitrate levels from the SIX pilot using three of the resins. It can be seen that the MIEX® absorbs two to three times less nitrate than the other resins (Koreman et al., 2009).

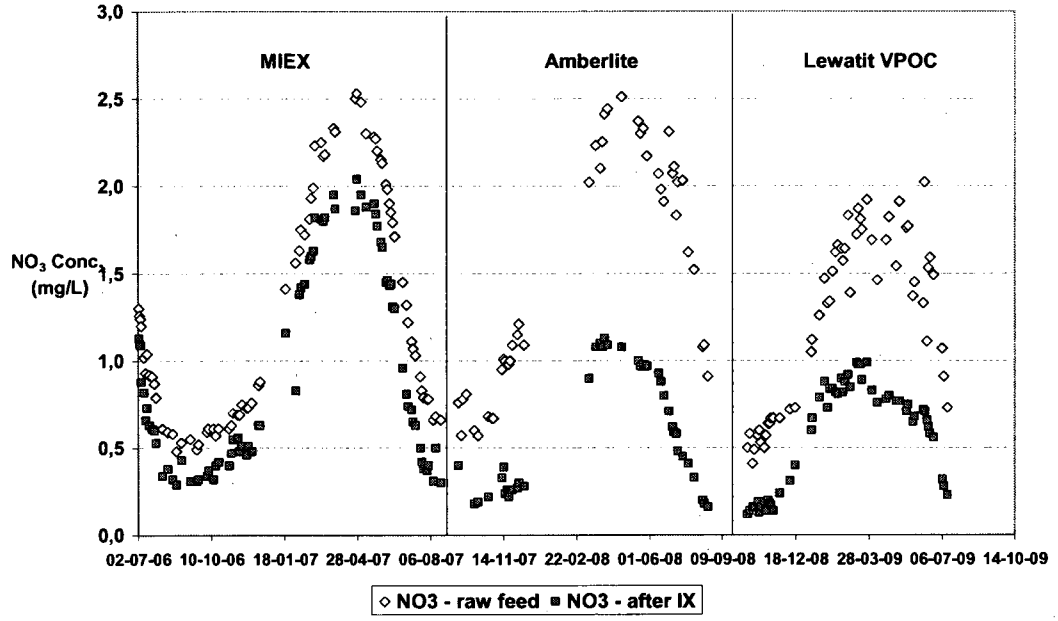

Figure 10 – Variations in nitrate removal capacities for the three major resins looked at by PWN for the SIX process.

The combination of the poor nitrate removals along with the other MIEX® issues that will be discussed in section 3.2.2 made it not a feasible option for PWN. The resin decision was then based primarily on economics and availability since the remaining resin performance levels were similar.

The resin decided upon for use in the long term trials at PWN was the Lewatit® VPOC 1071 Anion Exchange Resin. This resin is an acrylic based resin using the trimethylammonium contact sites making it a type I strongly basic ion exchanger according its Materials Safety Data Sheet (MSDS).

Being a strongly basic type I exchanger means that the bonds between the ionic species in solution and the resin are very strong and therefore there is little to no leakage from the resin during the contact period. It also means that more regenerant is required to reverse the equilibrium conditions and regenerate the resin.

3.1.3 Resin Hydraulic Characteristics

Not all resins are equally suitable in the SIX process because not all resins can easily settle out of suspension. The MIEX® resin being magnetic and able to bond to itself is ideal for settling and is why it was developed. When the MIEX® resin particles stopped mixing in the contactors, the magnetic forces were able to take over and the small particles bonded together to make larger particles that settled out of suspension rapidly.

Yet not all resins need to be specially engineered to settle out of suspension though. Jelly resins such as the Lewatit® resin used in these trials typically have densities less than water when they are dry but when they become saturated, have densities slightly greater than water and will settle (see Appendix B).

If a resin was to be used that was not magnetic, then a more efficient system needed to be created for the separation. PWN developed an innovative plate settler to address the problem of poor resin settling characteristics. These settlers allow for the rapid separation in a small space of resins with densities slightly greater than the fluid they were suspended in.

3.2 Ion Exchange Process Application

3.2.1 Contact Vessels Used in Ion Exchange

For an ion exchange process to take place the resin must interact with the feed stream resulting in the need for contact vessels. There are two main types of ion exchange

contactors and those are down-flow fixed bed contactors and up-flow fluidized bed contactors (Wachinski, 2006).

Fixed bed contactors are the most common in water treatment. In this method the untreated solution is pumped into the top of the contact tank and allowed to percolate by gravity downwards through a compact (unexpanded) bed of ion exchange resin.

To apply fixed bed contactors to raw water Wachinski, 2006 reports a system of coagulation and then filtration with either sand filters or membranes is necessary. The filtration step removes the suspended and colloidal matter that foul the bed and "coat the beads and granules of the ion exchange resin". This makes fixed bed contactors complex to use on raw drinking waters without extensive pre-treatment or frequent backwashing and flushing of the system.

The second predominant type of contactor is the fluidized bed system. This system injects the untreated water into the contactor from the bottom of the contact tanks with enough velocity to partially suspend the resin and results in an expanded resin bed. This expansion allows for the water to flow more easily around the resin beads and reduces the amount of fouling, but at the same time reduces the variation possible in the process.

The fluidizing in fluidized bed systems is dependent on the rate of flow, the viscosity, and the temperature of the solution. These dependencies limit the ranges in which the system can operate. When treating surface water with temperature and viscosity variations, maintaining a proper fluidized condition is difficult and therefore not often used in drinking water treatment (Wachinski, 2006).

Since these two types of contactors have complications with surface water treatment, it was necessary to look in another direction for a third type of contact system in which the previously mentioned issues could be avoided.

3.2.2 PWN Perspective on MIEX®

The MIEX® process was a revolutionary ion exchange unit developed in Australia in the 1990s. It had large advantages over other traditional ion exchange systems in that it was a "truly continuous ion exchange process" (Slunjski et al., 2000). The system was designed for the removal of natural organic matter (NOM), especially the dissolved fraction (DOC) in drinking water treatment.

The MIEX® system could be used to replace a traditional primary drinking water treatment system of coagulation and flocculation. The system was developed to avoid the standard pitfalls of traditional ion exchange such as only being applicable to small sized waterworks and the need for frequent flushing and cleaning of the resin (Slunjski et al., 2000).

MIEX® stands for Magnetic Ion EXchange resin and it was the development of this innovative resin that allowed for the process. Since the resin had magnetic properties it would settle out of suspension rapidly after conglomerating. This allowed for quick separation of the resin from the treatment stream. The MIEX® process uses 2 to 3 small constantly stirred reactor tanks (CSTRs) in series for the resin contact. The process withdraws approximately 10% of the resin continuously for regeneration and reinjection back into the process. In this manner the process is continuous and the resin stays in

suspension no matter the water quality making it "...not require any pre-treatment and produce water of a consistent quality..." (Slunjski et al., 2000).

The concept of the continuous process and the lack of pre-treatment appealed to PWN and it decided to adapt the MIEX® system to fit its specific needs. First the number of CSTRs in series (2 to 3) was not as many as PWN felt would be necessary to treat its surface water source. Two or three CSTRs is not as efficient as more contactors in series behaving close to an ideal plug-flow reactor.

Also the regeneration process continuously removing about 10% of the resin left 90% of partially spent or completely spent resin left in the contact tanks (Slunjski et al., 2000). PWN decided to completely remove the resin and regenerate it in a batch method instead of a continuous method. This helped ensure more consistent resin characteristics from the beginning to the end of the process.

With these concerns and adaptations in mind, PWN developed the innovative form of ion exchange known as Suspended Ion eXchange (SIX). The contactors were adapted to act hydraulically as more CSTRs in series, the resin regeneration process was turned into a batch process to increase regeneration efficiency, and a new type of lamella plate settling unit was developed to make the process usable with multiple types of resin. In this manner PWN was able to develop an effective ion exchanger that could be applied to its specific needs from its surface waters with a variety of resins.

3.2.3 Hydraulic Characteristics of SIX Contactors

There are two primary types of hydraulic reactors, ideal plug-flow reactors (PFR) and constantly stirred tank reactors (CSTR). Ideal PFRs assume that "over any cross-section normal to the fluid motion the mass flow rate and the fluid properties are uniform

and there is only negligible diffusion relative to the bulk flow...meaning that all fluid elements have the exact same residence time." (Ramaswamy et al., 1995). This is ideal because the exact amount of time the contaminants in the waste stream interact with the resin is known and at the maximum possible level. This creates the highest concentration gradients possible as the mass flowing through the reactor moves as a slug with minimal diffusion or dispersion meaning it stays concentrated and is only reduced by a reaction. This also allows for precise modeling since equal contact times mean equal and predictable treatment.

One way to approach an ideal PFR is to create a reactor that acts like multiple CSTRs in series. One CSTR doesn't have high concentration gradients to drive the reaction because theoretically, the moment the fluid enters the contactor; it is at the final effluent concentration because of the instantaneous diffusion and dispersion. But if multiple CSTRs are placed in series, the overall concentration gradient is increased because from reactor to reactor there are concentration gradients as the fluid becomes increasingly treated (Ramaswamy et al., 1995).

CSTRs are preferred in water treatment as opposed to basin contact tanks (where the water just flows in and there is no mixing) because even distribution and flow are easier to achieve and maintain under varying conditions (Ramaswamy et al., 1995). The SIX developed by PWN is designed to behave like multiple CSTRs in series.

With any system no matter the type of contactors, the specific characteristics of the flow through the contactor must be understood and documented to know how the resin and treatment stream are interacting. To understand how a contactor is working, residence time distributions (RTDs) are often performed (Ramaswamy et al., 1995). A

RTD study is when a tracer compound is injected into a reactor, monitored, and then analyzed to determine how the fluid flow through the reactor is behaving.

The first step in an RTD study is choosing an appropriate tracer. The tracer must be easy to measure in-line, readily available, and not degrade or change while in the reactor (Ramaswamy et al., 1995). For modeling the SIX, a highly concentrated salt solution was chosen as the tracer because large aqueous salt tanks were available (from the resin regeneration process), in-line conductivity readings can be taken easily and quickly with conductivity meters, and the aqueous salt would not react with anything in the tank once the resin was removed.

Hydraulic modeling is done by measuring and then using a system of equations to find unique coefficients and hydraulic values. The first figure that needs to be known in hydraulic studies is the theoretical hydraulic retention time (HRT). This is the amount of time it would take every particle to travel through the system if the flow is ideal and uniform over the entire contactor. It is predicted by dividing the total volume of the resin contact tanks and attached piping by the flow through the system as can be seen in *Equation 2.*

$$HRT = \frac{Volume}{Flow} = \frac{m^3}{m^3/hr} = hr \qquad \textit{Equation 2}$$

The curves generated from measuring conductivity over time are known as C-curves. These curves are used to create the cumulative distribution function, known as the F-curve, *Equation 3*, which can be in turn used to predict a mean residence time (MRT) for any dissolved or suspended item (i.e. resin). The MRT is calculated from where the F value = 0.500 (or 50% passing).

$$F = \frac{C_i(t)}{C_o}$$ *Equation 3*

Where: $C_i(t)$ = the absolute conductivity at any time t (mS/m)
C_o = the absolute maximum conductivity over the trial (mS/m)

The MRT is used along with *Equation 4* and *Equation 5* to calculate the number of theoretical completely stirred tank reactors (CSTRs) in series for the two reactors. The calculation for the CSTRs in series also uses the F values, but instead of being plotted against time, they are plotted against Θ. The calculation used to determine Θ can be seen in *Equation 4.*

$$\Theta = \frac{t}{MRT}$$ *Equation 4*

Where: t = time (minute)
MRT = mean residence time predicted with the F-curve (minute)

Once the F(Θ) curve has been developed for the trial, it can be compared to theoretical F(N,Θ) curves for various CSTRs in series using *Equation 5* (Bakker et al., 1996).

$$F(N,\Theta) = 1 - e^{-N*\Theta} * [1 + N\Theta + \frac{1}{2}(N\Theta)^2 + \ldots + \frac{1}{(N-1)!}(N\Theta)^{N-1}]$$ *Equation 5*

Where: N = Number of theoretical CSTRs in series

$$\Theta = \frac{t}{MRT}$$

Once the F(N,Θ) and F(Θ) curves are generated they are placed on the same chart and checked visually for comparison. Typically multiple F(N,Θ) curves are placed on a chart with one experimental F(Θ) curve.

These two parameters (the MRT and the CSTRs in series) are both indicators of the hydraulic characteristics and how well a system is working. The MRT based on the experimental data compared to the theoretical HRT is used to determine the level of short-circuiting in the flow or dead zones in the system where pockets of water are created and not being treated properly. The closer these two times are, the better the flow characteristics. The CSTRs in series is an indication of the approach of the ideal plug flow condition. The more CSTRs in series that the reactors act like, the closer the system is to reaching plug flow and the better treatment is in theory (Bakker et al., 1996).

3.3 Cyclic Ion Exchange with Biological Denitrification, Nanofiltration, and Reverse Osmosis

The waste stream of ion exchange resin regeneration fluid contains high levels of salt still in solution but also contaminants from the resin. To reduce this waste stream and the salt losses from the process, a treatment and reuse step can be considered. Introducing this step creates what is known as a cyclic operational ion exchange or brine reuse. For the SIX process, it is desired to apply cyclic operation in order to minimize the amount of salt used and sent into the waste stream.

3.3.1 Cyclic Ion Exchange

Previous research has been done in the field of brine recycling for reuse in ion exchange units (Bae et al., 2002; Korngold et al., 2005; Tokmachev et al., 2008). Many of these research projects did nutrient removal (Bae et al., 2002) or hardness removal (Tokmachev et al., 2008) to help reestablish the efficiency of the salt, but they did not concentrate the solution afterwards. The treated brine was used directly and supplemented with salt as needed to maintain the desired concentrations. It was noted in the cited literature that the pretreatment and contaminant removal was needed to be make brine reuse feasible.

3.3.2 Denitrification

Nutrient removal is a key component in making cyclic ion exchange a possibility. One of the main nutrients that is adsorbed from the feed water by the resin is nitrate. When the resin is regenerated, the nitrate is removed and ends up in a concentrated level in the used regeneration stream. This needs to be removed from the regeneration fluid before the fluid can be reused on the resin to reestablish the needed concentration gradient for desorption.

Denitrification is a common practice with ion exchange units used in groundwater drinking water treatment or industrial processes (Liu et al., 1996; Shain et al., 1988; Tokmachev et al., 2008). It is also a common practice in fish ponds, especially a fixed media biological process, where high nitrate levels from the fish are common (www.absolute-koi.com).

The current proposal is to remove the nitrate with a biological denitrification step using the fixed media contactor UltraBead® UB-140. This process operates by having an

aerobic zone with bacteria to reduce the oxygen levels in the water, then an anoxic or anaerobic zone with bacteria that can consume and reduce the nitrate down into nitrogen and oxygen gas. The reduction of nitrate is achieved by assimilation of the nitrate into the bacteria in both zones and in the respiration process of the bacteria in the anoxic zone.

The fixed film denitrification process has showed promise in the pilot scale trials. The removal percentages of the UltraBead® contactors if managed properly can be 97% to 100% if all of the required nutrients are available and the proper conditions are maintained. These proper conditions are the nitrate levels, the assimilable carbon concentration, the ratio of nitrate to phosphate, the amount of oxygen in the fluid that allows for the anoxic zone, the temperature, and the pH.

If all of the variables are properly maintained, good removals that are able to be modeled and predicted can be generated and the nitrate can be removed from the regeneration fluid with the biological step.

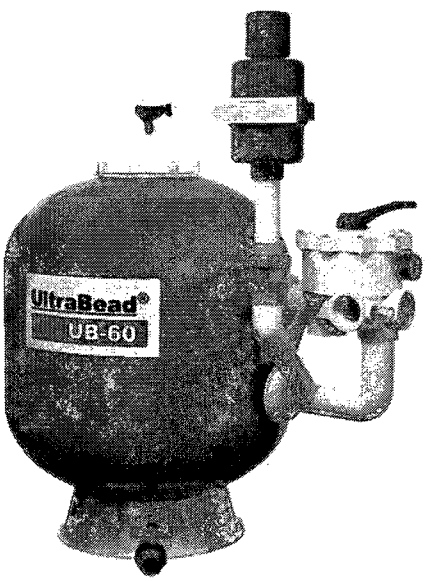

Figure 11 - Image of an UltraBead® Filter used for Denitrification in regeneration solution reuse of the SIX system.
Photo courtesy of www.absolute-koi.com

The denitrification process is being investigated and researched simultaneously to this research and is being conducted by another researcher at PWN (Bresson, 2009).

3.3.3 Membrane Filtration

Membrane filtration is a separation process where a feed stream is divided into a cleaned stream (called permeate or filtrate) and a concentrated stream (called concentrate or retentate) as shown in *Figure 12*. The process works primarily by forcing the feed stream across a semi-permeable membrane surface that acts as a barrier against specific compounds based on size. The forcing is typically done by pressurizing the feed stream and "pushing" part of the stream through the membrane while excluding the compounds that are too large to fit through the membrane pores (Verliefde et al., 2008).

Membranes can be applied in various practices ranging from desalinating drinking water or agricultural waters (Abulnor et al., 2002; Darwish et al., 2008) to nutrient removal (Cevaal et al., 1995) to fruit juice concentrating (Jiao et al., 2004).

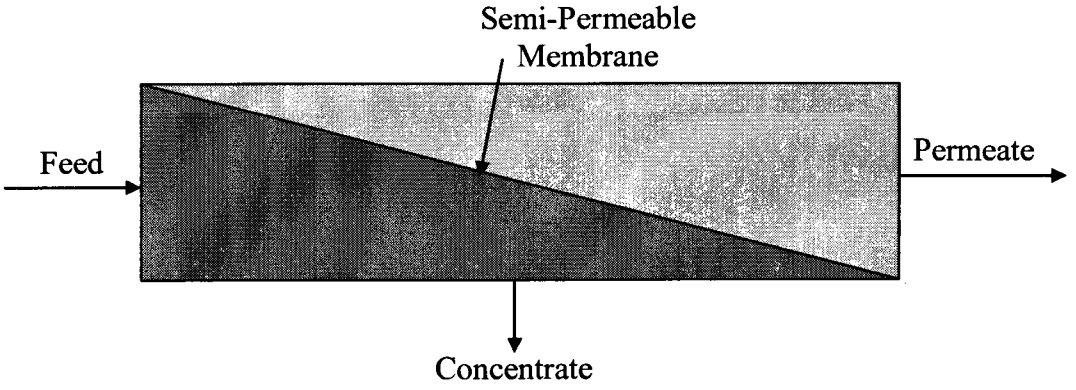

Figure 12 – Schematic of membrane filtration by separating a feed stream into a concentrate and a permeate stream using a semi-permeable membrane.

There are four basic types of membranes based on pore size. These are microfiltration (>100nm pore size), ultrafiltration (5-100nm pore size), nanofiltration

(0.5-5nm pore size), and reverse osmosis (0.1 – 1nm pore size) (Verliefde et al., 2008). These sizes and their subsequent exclusion potentials can be seen in *Figure 13*. The figure can be understood as anything list above and to the right of the specific type of membrane will be highly rejected by that membrane.

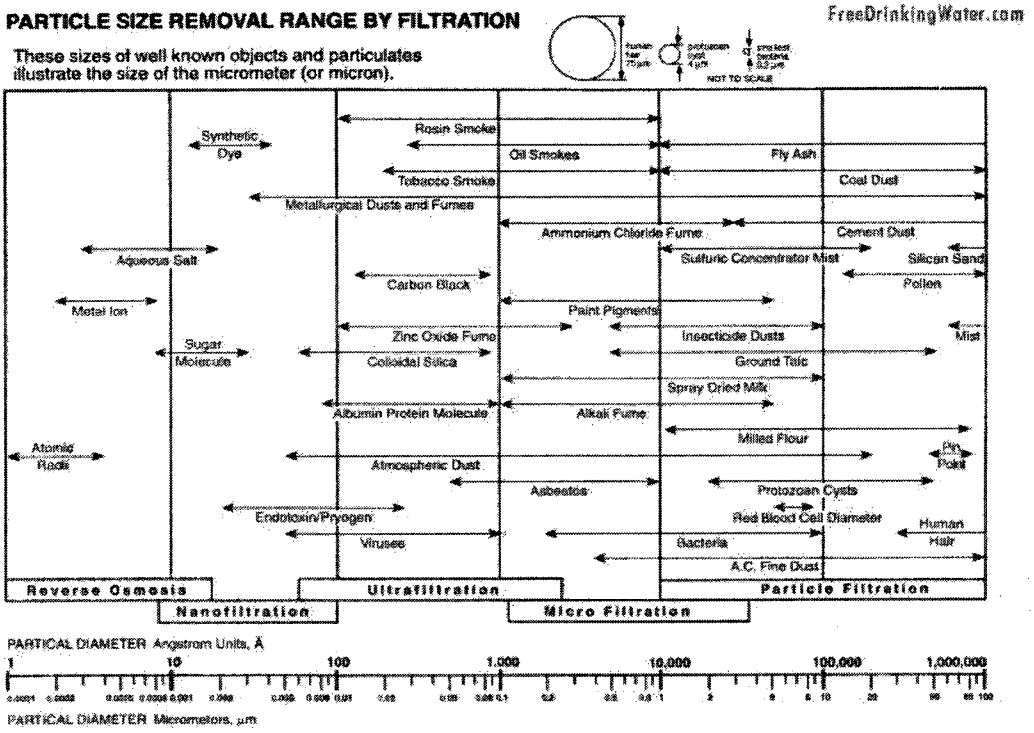

Figure 13 – Size exclusion chart for various compounds by the four main types of membranes and traditional particle filtration.
Photo courtesy of: www.freedrinkingwater.com

3.3.3.1 DOC Removal with Nanofiltration - *Figure 13* shows that nanofiltration retains very small organic molecules such as simple sugars and dyes while allowing the majority of aqueous salts to pass. A nanofiltration membrane should reject 95% to 99% of organic acids at the operating pH of between 7 and 8. Organic acids are the smallest

organic compounds and should have the lowest rejection rates. Also removal of organic acids is highly dependent upon pH. Monovalent salt rejection is expected to be minimal for NF at less than 5% unless there is heavy fouling of the membrane (Verliefde et al., 2008).

RO membranes (and NF membranes) are produced with varying materials and types of construction. There are cellulose acetate membranes, polyamide membranes, thin film composite, etc (www.kochmembranes.com). These different types of membrane will have different properties depending on the conditions. The different types of membrane material are however out of the scope of this research and will only be discussed minimally.

There are four physical distinctions in membrane construction: hollow fiber, spiral wound, tubular, and plate and frame. The first two have been proven to be the most economical to construct and are therefore the most commonly applied, especially under high pressure and high temperature conditions (Crowder et al., 1997). Because of this they will be the two focused on primarily.

The hollow fiber has the advantage of allowing mechanical cleaning and a larger area-to-volume ratio. The spiral wound has the major advantage of having a much cheaper membrane replacement cost (M&E Reuse, 2007). The two types are similar in most other ways so the two different types will need to be tested to see which one performs better, which has better life cycle costs, etc.

Hollow fiber membranes are composed of long thin hollow tubules in which the feed water is pressured on the inside of the tubules. The feed is forced through the membrane walls to the outside of the tubules where the permeate is collected. Spiral

wound elements consist of sheets wrapped around each other in a circular or spiral shape (*Figure 14*).

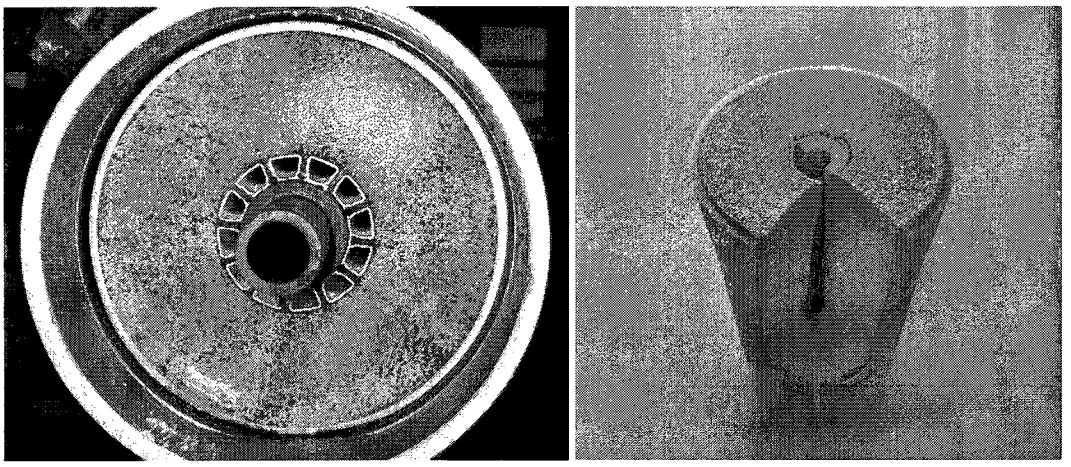

Figure 14 – 8 inch hollow fiber membrane (left) and 4 inch spiral wound membrane (right).

Over time as membranes are in use, the compounds that they are rejecting can accumulate on the surface or in the pores of the membrane. This collection of contaminants reduces efficiency and increases the pressure needed to operate the filters. This process is known as fouling (Verliefde et al., 2008).

One specific type of fouling that can occur with a membrane that rejects ions, usually nanofiltration and reverse osmosis, is inorganic scaling. Precipitation is the concentration of soluble ions in solution to high enough levels that solids are formed (Cornelissen, 2007). These solids tend to collect on membranes because of the concentrating process and can block the pores causing the fouling.

The following two equations are used to predict the chance of the ions combining and forming solids. If the solubility constant product (K_{sp}) value calculated, *Equation 7*,

with the expected ion levels of the concentrate is above the equilibrium value, then precipitation is likely to occur. The equilibrium values are based on clean water standards from laboratory data and are therefore just estimations when being applied to complex water such as a regeneration waste stream. It should be noted that in K_{sp} calculations the concentrations are measured in molarity and solids always have a value equal to 1.0 (Wachinski, 2006).

$$xA + yB \leftrightarrow AB_{(s)} \qquad \textit{Equation 6}$$

$$K_{sp} = \frac{[A]^x \cdot [B]^y}{AB_{(s)}} \qquad \textit{Equation 7}$$

All membranes will eventually foul whether it is from precipitation or just from a buildup of organics and particles in the pores. It is often too expensive and time consuming to replace a membrane every time it fouls. Therefore a cleaning process may be necessary. (Verliefde et al., 2008). In this research the cleaning process used was a forward flush.

The forward flush is done by replacing the feed stream with a clean water source such as the permeate stream or drinking water and quickly passing this stream over the membranes. The flush can be done with multiple cleaning agents added to the clean water source and often is to reduce biological buildup and chemical precipitation (Verliefde et al., 2008). In addition to chemical cleaning with biocides and anti-scalents (precipitant reducers), air can be added to the clean water flush to improve the flushing capacity and reduce fouling by over 50% (Cornelissen et al., 2007).

Since the DOC concentration in the feed stream is very high (ranging from 600mg/L to 800mg/L) and the flows are very low (200 to 350 L/hr) a recirculation system will need to be used. The reason for the recirculation is if the velocities at the

surface of the membrane are low then precipitation and fouling is heavily increased by the slow movement of the compounds. The slow movement gives the compounds more time to react and bond together (Verliefde et al., 2008). This is known as concentration polarization and is described by the environmental studies department at Yale University as the "accumulation of excess particles in a thin layer adjacent to the membrane surface." (Wargo, 2009).

Conversely, since the feed water is similar to an industrial waste with its high DOC and ionic concentrations, the cross-membrane velocity is kept lower and a second pump is used to maintain the higher tangential flow to keep the fouling of the membrane's internal pores to a minimum. This fouling can be irreversible and happens when the large organic particles are forced into the pores too fast. Therefore the cross membrane flux needs to remain within certain low ranges to reduce the fouling (Duranceau et al., 2001). Since flux is dictated by velocities and concentrations, if one increases (the concentration) then the other must decrease (velocity) to maintain a flux within the desired range. With a high surface velocity and a low cross membrane velocity needed for this feed, the conditions dictate the need for a high recirculation flow.

Previous trials were run at PWN with hollow fiber membranes. The hollow fiber membranes under the heavy DOC loading and high ion concentration levels would break or rupture in less than 24 hours contaminating the permeate and making it impossible to do any studies or collect any data. Because the hollow fiber could not be used without problems, it was proposed to use spiral wound membranes for future studies.

3.3.3.2 RO for Salt Concentration - Reverse Osmosis (RO) is a membrane filtration process similar to NF, but it differs in that it removes solutes from 0.1 to 1.0 nm

in diameter which includes monovalent ions such as chloride and sodium. For RO the feed pressure ranges from 5500 to 8500 kPa (800 to 1200 psi) to force a solution to go against an osmotic pressure gradient. It creates similar permeate and concentrate streams to the NF, just with different rejection levels. A RO membrane can isolate greater than 90% of ions while only rejecting 10% to 15% of the water that passes through it. This greatly increases the concentration of the retentate stream while diluting the feedwater (M&E Reuse, 2007).

RO desalination of seawater has been well described in literature (Sarkar et al., 2008; Zach-Maor et al., 2008; Darwish et al., 2008; Ebrahim et al., 1994; Khawaji et al., 2008; Cevaal et al., 1995). While these studies focused primarily on the permeate or the cleaned stream, they all still generated a concentrate stream. In the cyclic ion exchange application, the concentrate stream is the primary interest for reuse as resin regeneration solution.

One of the differences between these studies and application for cyclic ion exchange is the rinse coming from the ion exchange may have a higher concentration of salt than typical seawater (40 to 50 g/L compared to 30 to 35 g/L respectively). The desired concentration level for the regeneration solution is very high at 100 g/L. The concentration needed to obtain a saturated solution is even higher at 360 g/L. Preliminary calculations with *Equation 8* and *Equation 9* found that an operating pressure of 70.8 bar for the 100 g/L concentration and 173 bar for the 360 g/L concentration (1020 and 2510 psi respectively) would be needed.

$\Delta\Pi = [(C_f+C_r)/2]*B$ *Equation 8*

Where: $\Delta\Pi$ = Average osmotic pressure across the membrane (atm)
C_f = Feed concentration
C_r = Retentate Concentration
B = 0.776 atm / 1000mg/L (given value for NaCl solutions)

$F_w = A(\Delta P - \Delta\Pi)$ *Equation 9*

Where: F_w = Water Flux Rate (gal/ft^2·day) = assumed to be 5.0 gal/ft^2·day
A = Water permeability constant (given for cellulose acetate membrane) = 0.32 gal/ft^2·day·atm
ΔP = Operating pressure of the RO unit (atm)

It should be noted that for the 100 g/L retentate concentration the pressure is within normal operating levels for high pressure RO but the 360 g/L retentate concentration requires pressures well above the normal operating level and therefore may not be possible even with a high pressure RO unit. See the appendix for detailed calculations of operating pressures.

As reported in many of the articles (Darwish, 2008; Mavrov, 1997; Sarkar, 2008; Zach-Maor, 2008) results of RO trials are highly dependent on the feed water dissolved constituent concentrations, pH, and temperature. Because of this, systems need to be optimized with pilot plants from site to site. Since the theoretical calculations show that RO can perform at the concentration level needed, it is important to start looking at the various options for RO membranes and types to test in order to determine which will perform the most cost effectively for the specific conditions of cyclic ion exchange.

CHAPTER 4

MATERIALS AND METHODS

4.1 Materials

4.1.1 The SIX Pilot

The installation used for all of the SIX pilot studies is depicted in *Figure 15*, *Figure 16*, and *Figure 17*. The pilot's hydraulic capacity is between $20m^3/hr$ and $50m^3/hr$. The rotation speed of the overhead paddle mixers can be set between 20 to 45 rpm. The installation has a total volume from resin injection point to contact tank two outlet of 17.8 m^3 yielding hydraulic residence times of 53 minutes at $20m^3/hr$ and 21 minutes at $50m^3/hr$.

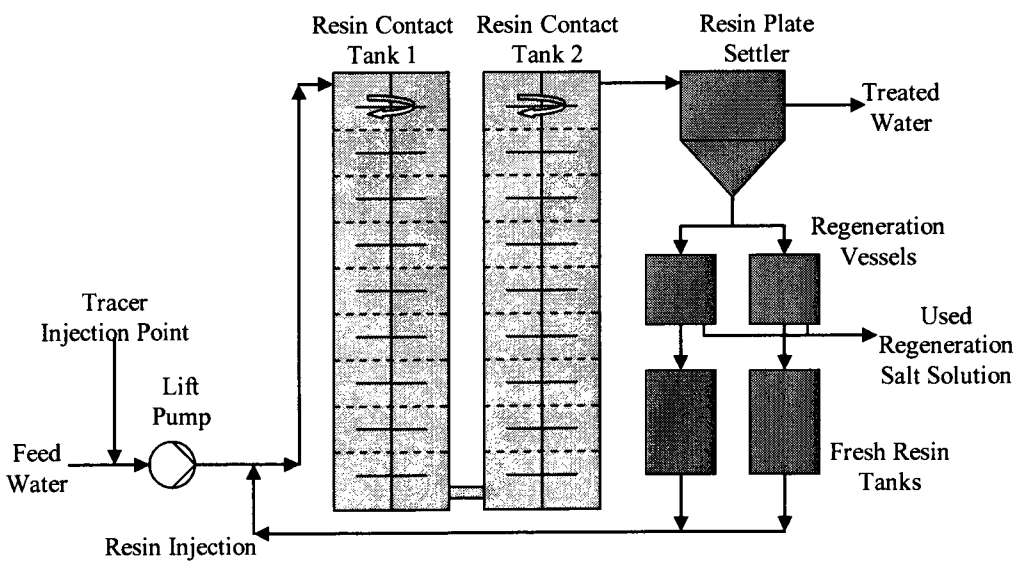

Figure 15 – Schematic of the SIX System.

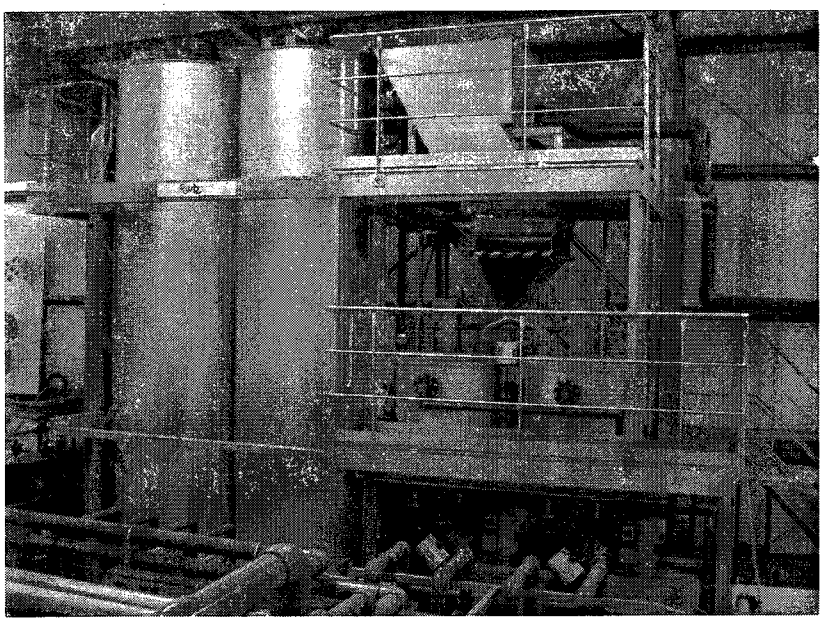

Figure 16 – Image of the SIX Pilot.

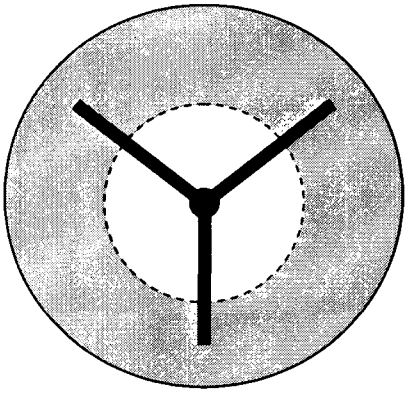

Figure 17 – Overhead view of the Resin Contact Tanks showing the three mixing paddles and the ring shaped baffles.

The resin is separated from the treated water by a plate settler and is then regenerated separately in the regeneration vessels. The resin injection rate can be modified in order to have resin concentrations from <1 mL/L to over 700mL/L. The typical concentration for the applied Lewatit® resin is approximately 10mL/L. The resin

is injected into the system directly after the feed pump by a by-pass flow. This injection system reduces the resin attrition compared to mechanical pump systems.

The two contact tanks have four sample ports along their lengths approximately every 1.5 meters. Representative sampling over the contactors can be done from these ports to determine the efficacy of the treatment process. The distribution of the sampling ports is presented in *Figure 18*.

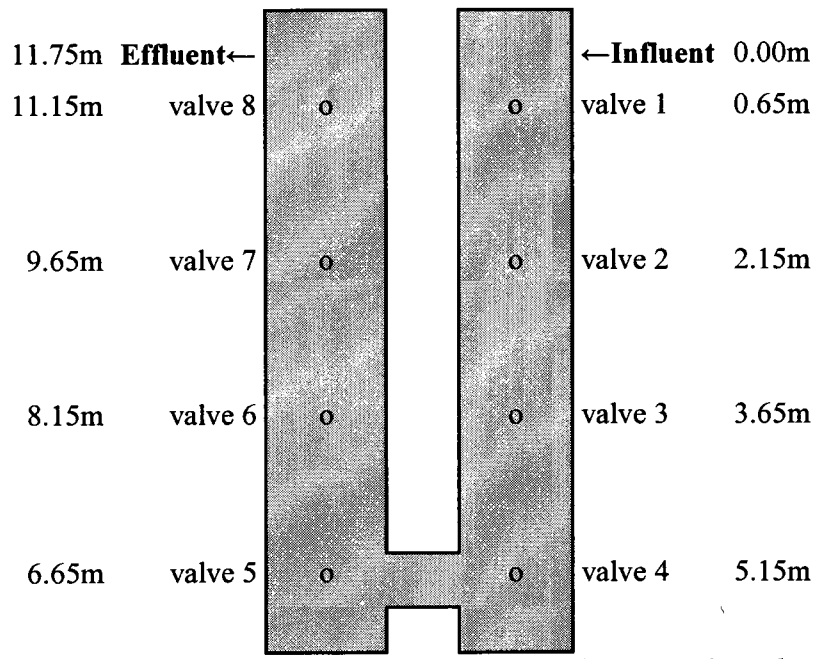

Figure 18 – Schematic of the sampling ports and their distances along the treatment process for the SIX resin contact tanks.

The resin is regenerated in a batch method process (*Figure 19*). The regeneration is a counter-current process meaning it is run using the twice used solution from salt vessel three first and the clean solution from salt vessel one last. The salt concentration in the salt vessels, the feed, and the effluent are given in *Figure 19* as well. The salt vessels

and the resin regeneration vessel all have a maximum capacity of approximately 1000L. Around 300L of each salt solution is used for regeneration being mixed with approximately 450L of resin. The mixing paddle in the vessel spins at 145rpm yielding a $165s^{-1}$ g-value. Each current regeneration step (the three salt steps and two final rinsing steps) take approximately 11 minutes resulting in a total regeneration time of 55 minutes total. For further details on all pilot installations see APPENDIX A.

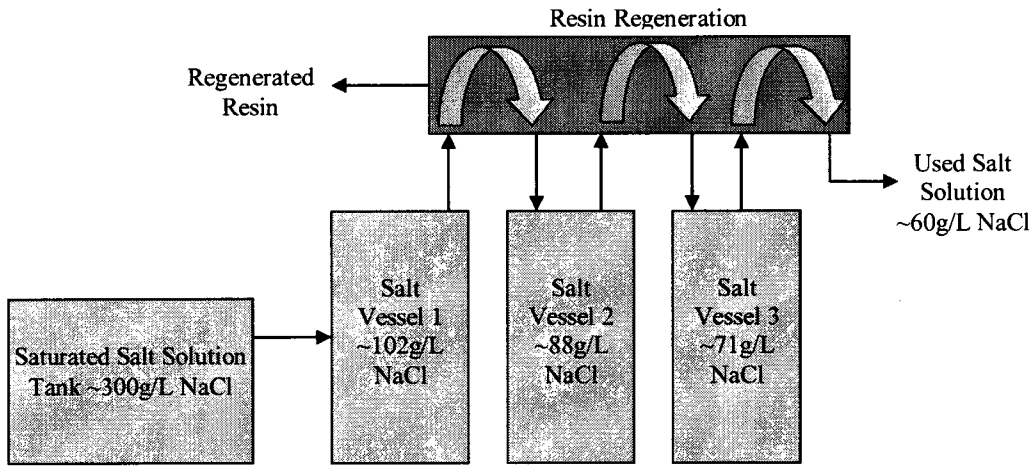

Figure 19 – Schematic of the current resin regeneration process. The process is counter-current and therefore works from right to left starting with salt vessel 3.

4.1.2 Jar Test Apparatus

The jar test apparatus used to model the resin desorption kinetics was an Aqua® Lytic Floc Tester. The apparatus has 6 stirring paddles that spin all at the same speed with six cylindrical jars used for the contacting. The stirring can range from 10rpm to 800rpm with only water in the jars and between 10rpm and 400rpm with the resin and salt solution mixture. To imitate the $165s^{-1}$ g-value found in the pilot, the stirring speed

needs to be set to 140rpm. The contact jars are clear plastic with vertical baffles to ensure adequate mixing. The jars have a maximum volume of 2.0L.

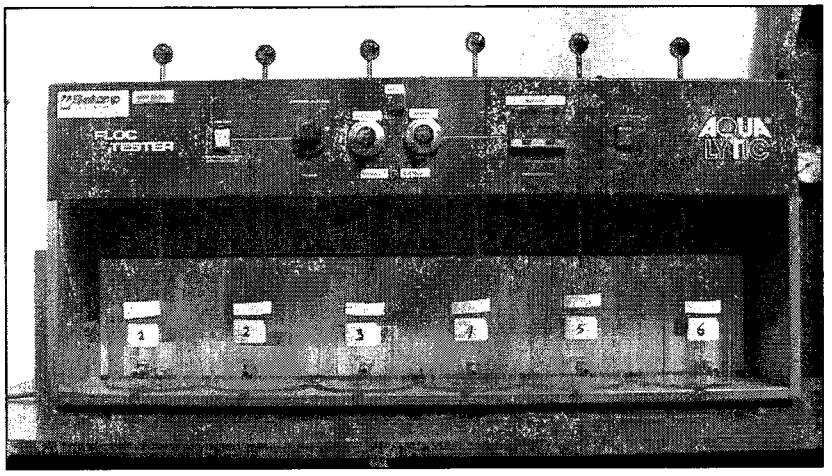

Figure 20 – Image of the jar testing apparatus used for the resin regeneration trials.

4.1.3 Nanofiltration Pilot

The nanofiltration pilot setup is a pre-built, skid mounted unit that was purchased from and installed by RWB Water Services, a local contractor. The unit has two 8-inch membrane pressure vessels set-up in parallel with a recirculation system built into the structure. The recirculation system has a total volume of approximately 110L when the pressure vessels contain membranes.

The permeate flow is controlled by a manually controlled valve and has a maximum of 600L/hr. The concentrate is expected to contain high levels of organic material resulting in the fouling of the piping and valve at low flows (40 to 70 L/hr). The system therefore operates in a pulse manner having a timer turned on every few minutes for a few seconds at high flows to keep the fouling to a minimum.

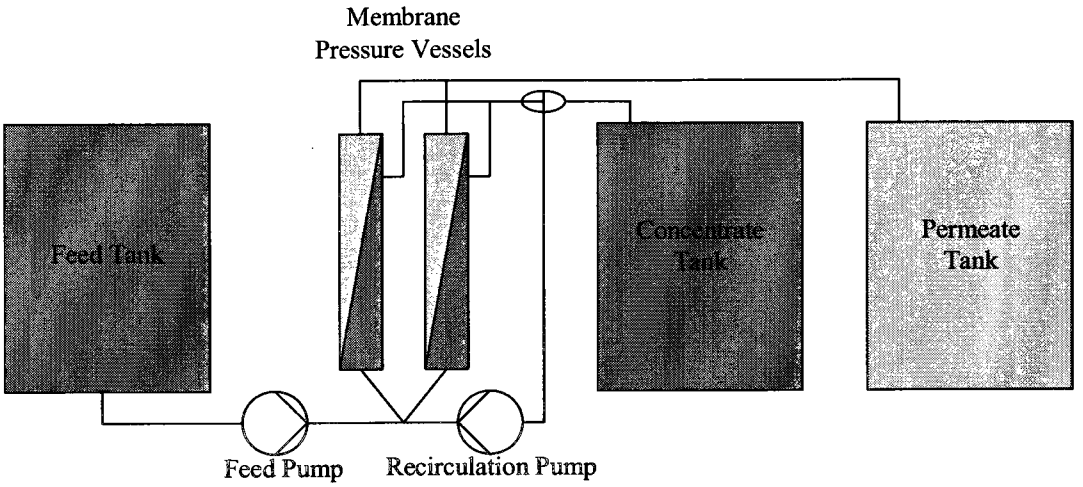

Figure 21 – Schematic of the NF Pilot Unit

The membranes used in the trials conducted were FILMTEC NF270-400 Nanofiltration Elements developed and built by the Dow Corporation. The membranes are constructed of polyamide thin-film composite and are spiral wound. These membranes are specially designed to remove a high percentage of TOC and THM precursors while have a medium to high salt passage and medium hardness passage according to their manufacturers' specifications sheet. These elements have a maximum operating temperature of 45^{oC} and a listed maximum pressure drop of 1.0 bar with a maximum operating pressure of 41 bar.

4.1.4 Denitrification Pilot

The denitrification process is a biologically active fixed media contactor system and provides the feed solution for the NF pilot. The vessels used for this system are two UltraBead® UB-140 filters that can be run either in series or in parallel. The UB-140 has a volume of 255L and can treat approximately 2000 g/d of nitrates. The filters are up-flow contactors and can handle up to $40m^3/d$ of treatment waters.

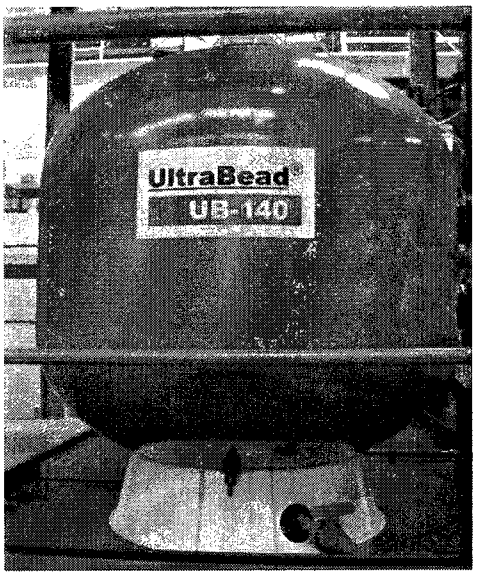

Figure 22 – Image of Pilot UB-140

4.1.5 Resin used in Desorption and Pilot Studies

Lewatit® VPOC 1071 Anion Exchange Resin was used in this research. This resin is an acrylic based resin having trimethylammonium contact sites making it a type I strongly basic ion exchanger according the Materials Safety Data Sheet (MSDS) produced by Lanxess. The material comes in a white, solid bead form with a bulk density of 0.72 g/mL and a saturated density of 1.08 g/mL. This saturated density is higher than water giving the resin its settling capacity. For further details on all materials used in the experiments see APPENDIX B.

4.1.6 Salt used in the Regeneration Process

The salt used in the trials is a granular sodium chloride salt that is 99.9% pure and has an average grain size of 0.38mm. The salt is supplied by AkzoNobel of Dordrecht North Holland and is termed "vacuum salt" by the supplier because of the vacuum system

that is used to separate out the salt crystals from a saturated solution. From this bulk material, a saturated sodium chloride solution is made.

4.2 Methods

4.2.1 Jar Test Desorption Operating and Sampling Procedure

The desorption studies were performed with spent resin collected just before regeneration from the regeneration tanks of the pilot. A portion of the samples were collected saturated in the partially treated water as the tank was filling. Another portion was collected after the tank had been drained dry by the under drain collection system. The samples that were saturated needed to be drained manually using a vacuum apparatus made from a vacuum flask, a funnel with a reusable filter, and a vacuum generated with a running faucet. Both methods, collecting dry and manually draining, yielded 275mL ± 15mL less water in the pores per liter of resin than in the saturated state. There is no distinction made in the experiments between the two collection methods.

Four duplicate jar test experiments were conducted, one set of experiments with each type of salt (clean, once used, and twice used) and another set with repeatedly using clean salt to determine the absolute concentration of DOC and nitrate on the resin.

For the jar test studies, 900mL of resin and 600mL of salt solution were added to the jars and set to spin with a $165s^{-1}$ g-force to mimic the regeneration vessels in the SIX system. The jars were mixed for their designated times of 5, 10, 15, 30, and 60 minutes. These times were chosen to establish best fit curves that could then be used for modeling.

The jars were taken from the apparatus after their designated contact time, allowed to settle for 30 seconds and then approximately 50mL of the solution was drawn

off the top and immediately filtered with a Whatman® 0.45 micrometer syringe filter unit to separate out the resin and stop the reaction.

To have comparable data, absolute desorption values for both DOC and nitrate were established along with the salt solution concentrations shown in *Figure 25* and *Table 3*. This allowed for the resin jars to be sampled after their contact time and measured directly with the spectrophotometer and then adjusted with the known salt solution concentrations.

The absolute values were established by using one sample of resin and repeatedly regenerating it for 10 minutes periods with clean salt solution. This was done by draining and rinsing in between the 10 minute runs with tap water and the vacuum apparatus previously mentioned. After each run a sample was taken and a cumulative graph was created to establish the absolute values as displayed in *Figure 25*.

4.2.2 Pilot Scale Regeneration Testing Procedure

Trials were conducted with the large scale pilot facility to compare the predicted regeneration efficiencies made from the model to actual observed efficiencies. This was done by making a prediction using the model for various contact times from the three salt solutions or just two of the salt solutions and then making the pilot mirror these time variations using the computer interface controls.

After the pilot settings had been changed the system was allowed to regenerate the resin twice before being sampled. The samples were taken out of the fresh (regenerated) resin tanks after the completed regeneration cycle. The samples were vacuum filtered to remove the excess water and 24 hour jar test studies were run on them to compare efficiencies. The 24 hour method was assumed to be absolute desorption.

These 24 hour studies were done by adding 600mL of the clean salt solution to 900mL of the regenerated resin and allowing it to stir in the jar apparatus for 24 hours. After 24 hours the UVT_{254} measurement procedure was performed to determine DOC concentration. The concentration in the solution from the resin regeneration subtracted from the maximum loading possible on the resin showed the efficiency of the individual regeneration step.

4.2.3 Hydraulic Characterization Studies

First for these studies all of the resin was removed from the system to ensure that it did not react with the salt tracer. The salt was then pumped from the concentrated salt solution into the main feed line before the lift pumps and conductivity levels at the influent, the midpoint, and the effluent of the resin contact tanks were monitored.

The salt injected into the system was at a concentration of approximately 300 g/L and at a flow of approximately 400 L/hr. The salt for the trials was taken from the saturated solution used to make the resin regeneration solution. The salt injection raised the feed salt concentration from approximately 80mS/m to 400mS/m causing a clear rise in the feed water conductivity for the trials allowing for clear conductivity curves to be generated.

The sampling points established at the influent point (the top of tank 1), the midpoint between the two tanks and at the effluent point (the top of tank 2) were monitored allowing for three curves to be generated and compared for each trial. One WTW Microprocessor Conductivity Meter LF3000® being recorded manually and two Hach HQ 40d Multimeters® recording automatically were used to measure the conductivities. The meters were all calibrated with a 78.1 mS/m solution of KCl. All

readings taken were left in or converted to a conductivity measurement of milliSiemens per meter (mS/m). Only the effluent curve as used in the hydraulic calculations.

The salt solution was pumped into the system for a duration starting with 2 times the theoretical hydraulic residence time (HRT) and then increasing to 3 times the HRT to allow for the conductivity to peak and then be at steady conditions before being stopped creating a clear leveling out of the data.

Two major elements of the pilot were varied to determine the optimal operating conditions. These elements were the feed flow and the mixing speed of the paddles. The flow was adjusted with the feed pump to ~25m^3/hr and ~50m^3/hr to represent the extremes that the system is designed to run at. The mixing speed trials were run with the paddles set to 20rpm, 32rpm, and 45rpm. These are a low rotational speed, the speed the system is typically run at, and a high rotational speed respectively. The rotational frequency adjustments were made manually on the paddle mixing motors.

4.2.4 Hydraulic Efficiency Studies

Two trials were run to compare mixing frequency effects on the performance of the system. The high and low flows were not compared because the system is intended to in the future only be run at the high flow levels. The two mixing speed extremes from the previous study were compared, 20rpm and 45rpm. The samples were taken from ports along the treatment process from inlet to outlet of the SIX system all at the same time.

These sampling ports and their distance along the resin contact tanks can be seen in *Figure 18*. Since DOC is the main constituent for removal in the SIX process, UVT_{254} will be used as a surrogate for DOC concentration.

The theoretical HRT for this experiment was approximately 20 minutes. Therefore to ensure that the installation is at equilibrium before being sampled it was run for 3 times its HRT (around 60 minutes) at the specified mixing speed. Then another sample was taken one HRT later (at around 80 minutes) to ensure that the system was at steady state and to have sample duplicates for the system without sampling the same water. After the samples were taken, they were run through a Whatman® 0.45micron filter as quickly as possible to separate out the resin from the sample and ensure that the reaction between the resin and the DOC was stopped.

4.2.5 Pilot Scale Nanofiltration Procedure

Before the installation could be run with the denitrification effluent, the clean system characteristics needed to be determined. For this the system was flushed with drinking water and the new membranes were installed. Then an extensive analysis of the feed water was run to identify potential fouling agents and precipitants. The initial analysis tested for the levels of the following compounds:

- Ca^{2+}
- Ba^{2+}
- Fe^{2+}
- Mg^{2+}
- Mn^{2+}
- Sr^{2+}
- CO_3^{2-}
- SO_4^{2-}
- PO_4^{3-}
- pH (for OH^- levels)

Based on these levels in the feed, potential precipitant formation was predicted and the recirculation stream on the membrane surface was determined. Simple K_{sp} calculations were run with the concentrations at five times their measured level. The

membranes will run at an 80% efficiency meaning the potential for a five times increase in the concentrations of the previously mentioned compounds.

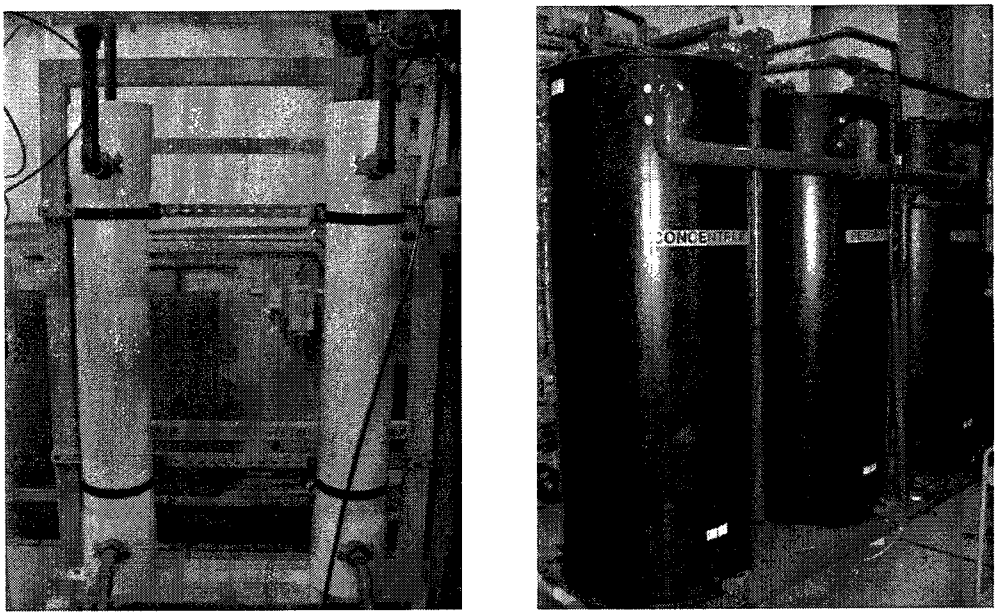

Figure 23 – Left: NF membrane pressure vessels
Right: NF pilot feed, permeate, and concentrate holding tanks.

The temperature of the pilot was monitored closely with an inline temperature gauge in the recirculation system. The temperature of the membranes could not exceed 45°C according to manufacturer's specifications. Therefore the temperature was monitored and recorded manually as well as a safety level set into the operating system. If the temperature exceeded 40°C for more than 30 seconds, the installation shut down.

The following variables and levels were used to control the NF system and determine if it could run on a continuous basis:

- Permeate Flow ~160 L/hr
- Concentrate Flow ~40L/hr
- Forward Flush Frequency ~1 time per hour
- Forward Flush Duration ~30 seconds
- Forward Flush Air Pressure ~6 Bar

The pressure in the feed line, the permeate line, and the recirculation line were recorded manually using an EN-837-1 built in pressure gauge. The trans-membrane pressure (tmp) drop was recorded as the difference between the feed line pressure and the permeate line pressure.

All samples, whether for the in-house analysis or the external laboratory analysis, were taken from the permeate, feed, and concentrate holding tanks. The permeate and feed samples were taken each morning of operation from a sample port along the bottom of the holding tank. The tanks were allowed to drain as needed so the samples were not 24 hour averaged samples. The concentrate was also sampled from the bottom sample port, but the concentrate was collected for the 24 hours from the previous sampling and mixed with a pump before being sampled.

To ensure the system was operating within acceptable ranges, the parameters listed in *Table 1* will be measured by the operator. The measurements taken every few hours will let the operator know if the installation is going to have any instantaneous failures such as melting of the membranes or pipes bursting. The daily measurements will be rough estimates on the efficiency of the system for monitoring purposes. This data will not be used directly for the final analysis.

Table 1 - Measured by the Operator for Rough Efficiency Estimates

Measured Every few Hours	Measured Daily
• Pressure drop over the membrane • Temperature of the recirculated water • Feed, Permeate, and Recirculation Flows	• UVT % (as a surrogate for DOC) • Salinity

For more detailed and accurate analysis of the NF installation samples were taken and sent to the professional external laboratory HWL. The specific samples and analyses can be seen in *Table 2* and explained in APPENDIX C.

Table 2 - Measured by an external laboratory

Measured Daily	Measured 3 Times per Week	Measured Once per Week
• NO_3 • DOC • Sodium Ions • Chloride Ions	• Any potential precipitants	• NOM Scans

4.2.6 Measuring UVT_{254} with a Spectrophotometer

The samples taken to measure UVT_{254} were diluted down to levels between approximately 65% and 90% with MilliQ water. The samples were then filtered with a 0.45µm Whatman® syringe filter unit to remove all large suspended matter that could interfere with a dissolved organics reading. Once filtered, the samples were run through a Hach/Lange DR 5000 Spectrophotometer. The UVT_{254} readings given were used to estimate the DOC concentrations. For the DOC measurements, the spectrophotometer measured Ultraviolet Transmittance (UVT_{254}) in percent absorption at a wavelength of 254nm. This wavelength has been shown to be a surrogate measurement for DOC concentration in treatment waters. The equation and graph used to equate UVT_{254} to DOC can be seen in *Figure 24*.

4.2.7 Relating UVT_{254} to DOC Concentration

All in house DOC concentration values were estimated by measuring the percent UVT_{254} first, then using the relationship established by PWN these readings were converted. The established relationship and the equation used can be seen in *Figure 24*. The relationship allows for UVT_{254} readings between approximately 65% and 90% meaning that DOC samples had to be diluted down to between 2mg/L and 6mg/L to be accurately read.

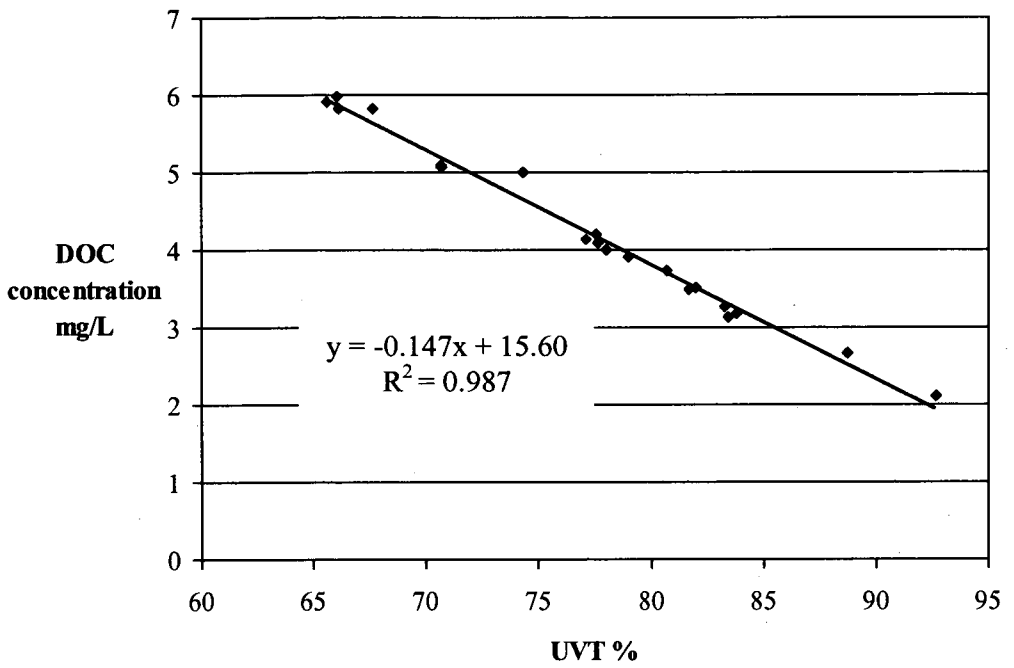

Figure 24 - The graph and equation used to equate UVT_{254} to DOC concentration established by Erik Koreman at PWN

4.2.8 Measuring Nitrate Concentrations

The in house nitrate measurements were taken using the same Hach/Lange DR 5000 spectrophotometer. The samples were diluted down to within a measurable range of between 1.0mg/L and 60mg/L and filtered using the 0.45µm Whatman® syringe filter to remove contaminants. Once the sample was filtered, the Lange LCK 339 nitrate measuring kit was used which has an MDL of 1.0mg/L. In this kit 1.0mL of the filtered sample is added to a test tube along with 0.2mL of a reacting agent into the fluid already in the tube. The tubes are then shaken and allowed to sit for 15 minutes before analyzing. This kit has a pre-programmed method for the Hach/Lange spectrophotometer.

4.2.9 Het Waterlaboratorium N.V. Haarlem

Het Water Laboratorium N.V. Haarlem (HWL) is a professional laboratory that is independent of PWN. HWL is the third party laboratory that was hired during this research to do certain analysis that the in-house laboratory was unable to perform.

HWL is accredited nationally by the Nederlands Normalisatie-instituut (NEN or Dutch Standardization Institute) and internationally by the International Organization for Standardization (ISO). The facility is accredited under NEN-EN-ISO/IEC 17025:2005 and will be until January 1, 2011. For the sampling standards and procedures used at HWL and its official accreditation, see APPENDIX C.

CHAPTER 5

RESULTS AND DISCUSSION

The results and analysis of the following chapter will directly correlate to and answer the questions posed in section 2.4 of the research description, the research questions and goals.

5.1 Resin Regeneration

5.1.1 Resin Regeneration Jar Test Results

Before the resin trials could be run, absolute capacities for the Lewatit® resin being used needed to be established. These are needed to have constants to compare not only all of the research in this report, but also to ground it for comparison to other research projects. The absolute capacity trials were done twice and the cumulative graph can be seen in *Figure 25*. The absolute concentrations established from this figure were approximately 1000mg DOC / kg of wet resin and 700mg nitrate / kg of wet resin.

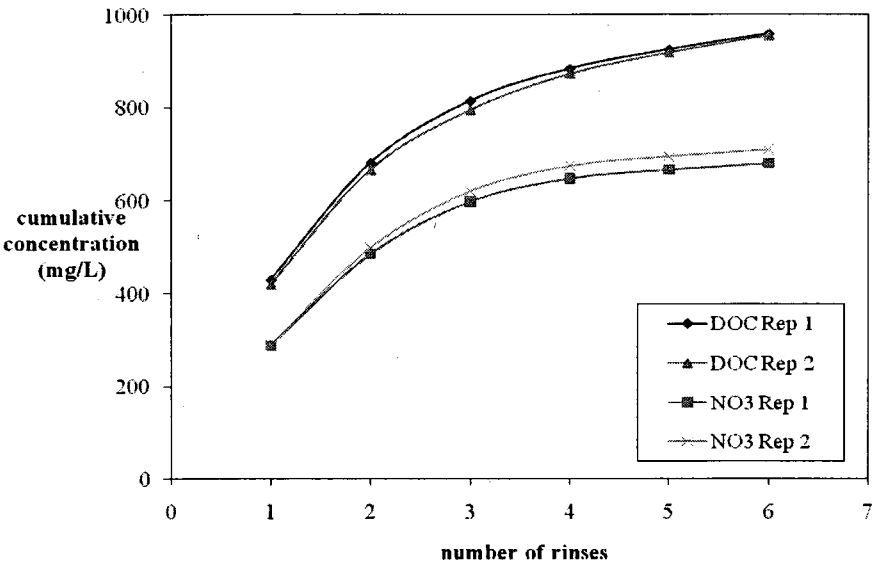

Figure 25 - Cumulative plots showing the absolute concentrations of DOC and NO_3 adsorbed onto spent Lewatit® resin run through the SIX process.

Next, the desorption kinetic studies were performed. The regeneration efficiencies compared to the absolute value already established of 1000mg/L DOC can be seen in *Figure 26* as well as the equations used to establish the system prediction model. *Table 3* in conjuncture with *Equation 10* was used to establish the percent efficiencies and the model equation.

Table 3 - Summary of the salt solutions used for the resin regeneration

	Clean Salt Solution		Once Used Solution		Twice Used Solution	
	Average	StDev	Average	StDev	Average	StDev
Salinity (g/L)	102.4	6.6	88.0	8.1	71.4	8.8
DOC (mg/L)	1.4		203	16.0	312	11.3
NO3 (mg/L)	7.0	0.1	185	15.3	311	7.3

The numbers produced by combining *Figure 26* and *Equation 10* completes the first research goal of modeling the resin desorption characteristics. It should be noted that only DOC measurements were used to predict and optimize the pilot. Although nitrate is

of major concern in this process, it reaches a state of equilibrium too quickly making curves impossible to be generated and use as predictions. Examples of this can be seen in APPENDIX F as well as the raw data from the resin experiments. The nitrate efficiencies were recorded in the pilot and it was noted that they followed the same trends as the DOC so for this research, it is not essential to model them as well.

$$\%DOC_r = \frac{DOC_m - DOC_s}{DOC_a} \bullet 100 \qquad \textit{Equation 10}$$

Where: $\%DOC_r$ = The percent of DOC removed during the salt regeneration
DOC_m = The concentration of DOC measured in the sample
DOC_s = The concentration of DOC measured in the salt solution
DOC_a = The absolute level of DOC on the resin established by *Figure 25*

The best fit curves generated in *Figure 26* were used to predict and model the regeneration efficiency of the pilot.

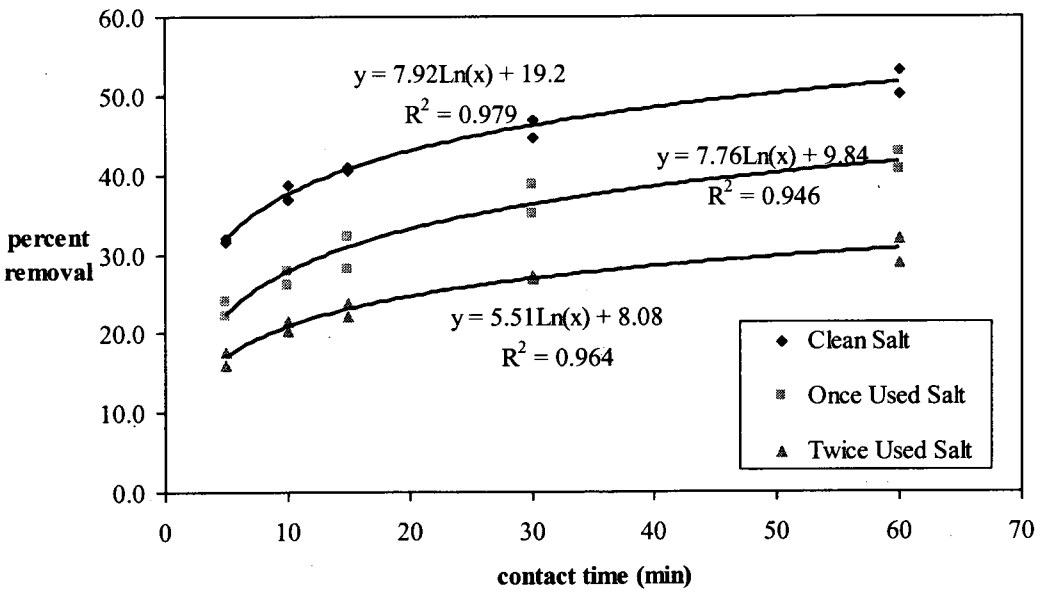

Figure 26 - The plots and best fit curves used to model the efficiency of the SIX pilot at PWN from the experimental jar tests.

The equations from these curves were used to generate *Table 4* in which it can be seen the predicted efficiencies of the pilot under various regimes. *Equation 11* shows how the predicted equations were used to compile a single efficiency percentage.

$$PE_T = [1-(1-\frac{PE_{clean}}{100})*(1-\frac{PE_{once}}{100})*(1-\frac{PE_{twice}}{100})]*100 \qquad \textit{Equation 11}$$

Where: PE_T = Overall Percent Efficiency for the entire regeneration process (percent)
PE_{clean} = Percent Efficiency for the clean salt for time t (percent)
PE_{once} = Percent Efficiency for the once used salt for time t (percent)
PE_{twice} = Percent Efficiency for the twice used salt for time t (percent)

The overall equation needed to predict the removal efficiency of the pilot can be seen in *Equation 12.*

$$PE_T = [1-(1-\frac{7.92Ln(t_1)+19.23}{100})*(1-\frac{7.76Ln(t_2)+9.84}{100})*(1-\frac{5.51Ln(t_3)+8.08}{100})]*100$$

Equation 12

Where: PE_T = Overall Percent Efficiency for the entire regeneration process (percent)
t_1 = contact time of salt from vessel 1 with resin in a CSTR (minutes)
t_2 = contact time of salt from vessel 2 with resin in a CSTR (minutes)
t_3 = contact time of salt from vessel 3 with resin in a CSTR (minutes)

The summary below shows the different efficiencies for different contact periods. Since each cycle is approximately 11 minutes long, 7 minutes in addition to the current 4 minute mixing time is gained each time a cycle is dropped. This leads to the times presented in the optimization table (*Table 4*).

*Table 4 - List of modeled contact times generated by using Equation 12 with the old regime and the new optimized regime in **bold**.*

Regeneration Time			Modeled DOC
Twice Used	Once Used	Clean	Removal Efficiency %
4	**4**	**4**	**53.3**
3	4	5	53.6
0	7.5	10	53.3
0	7	12	54.1
0	8	11	54.2
0	**9**	**10**	**54.3**
0	10	9	54.2
0	11	8	54.0
0	0	26	45.0

Elimination of the twice used resin did not significantly reduce the percent DOC removal, but the elimination of the once used and the twice used salt solution did significantly reduce the percent DOC removal.

The bolded sections of *Table 4* completes the second research goal which is to use the model to predict pilot efficiencies and determine if the current regime is optimal. It is also worth noting that with the new optimized system, a minute and a half can be removed from the overall time while maintaining the same removal efficiency as the current method. This can be seen summarized in lines one and three of *Table 4*. See APPENDIX D for the raw data on the pilot trials and the optimization.

5.1.2 Pilot Studies

To check the accuracy of the prediction model, pilot studies were run for comparison purposes. It can be seen that the optimized regeneration method for running the system follows the models generated with the jar tests closely. *Table 5* is the completion of the third research goal which was comparing the model to actual pilot data.

Table 5 - Summary of model predicted efficiencies vs. pilot experimental efficiencies with the differences between the predicted and measured values bolded.

	DOC Model	DOC Pilot Data	NO_3 Pilot Data
Current Method of Regeneration	53.3%	58.4%	82.8%
"Optimized" Method of Regeneration	54.3%	59.7%	84.4%
Increase in Regeneration Efficiency	**1.0%**	**1.3%**	**1.6%**

From *Table 5* it can be derived that the predicted efficiencies were both approximately 5% below the actual efficiencies. The pilot runs the regeneration fluids sequentially from twice used to once used to clean salt solution to increase the concentration gradient of the salt while the jar test models were all run individually with just the twice used, the once used, or the clean salt solution. Therefore the efficiencies of the pilot are expected to be slightly higher. Also it is worth noting that the nitrate desorption efficiency of the system increased as well as the DOC desorption efficiency, confirming that the nitrate trend follows the DOC trend and separate nitrate desorption modeling is not necessary.

5.2 SIX Hydraulic Characteristic Studies

It should be first noted that the hydraulic characteristic studies were all conducted using a dissolved tracer (sodium chloride salt) and not a particle tracer which would have been a more accurate representation of the resin beads. The reason for this is based on the readily available equipment and raw materials located at the pilot (salt and conductivity probes). These were a more feasible and readily available option as opposed to procuring more equipment and materials (such as particle tracing equipment and tracer particles).

5.2.1 Pilot Flow Characteristics Studies

The following sections contain the data gathered and analyzed during the flow characteristic studies conducted on the SIX contactors. The operational variations for these trials were the feed flow into the system and the rotational frequency of the paddle mixers. The pilot was run at low flows of around 25m^3/hr and high flows of around 50m^3/hr to test the extreme operating conditions. Secondly the mixing frequencies were varied from 20rpm to 32rpm to 45rpm to represent the two extreme potential mixing conditions within the restrictions of the pilot and the average operating conditions of the pilot. Tracer study raw data is presented in APPENDIX E.

5.2.1.1 23.4m3/hr and 32 rpms - The first trial conducted for the flow characteristic studies was conducted by running the pilot facility at a flow of 23.4m^3/hr with the paddles set at a mixing frequency of 32rpms. These were the default settings that the installation was running at during the research period.

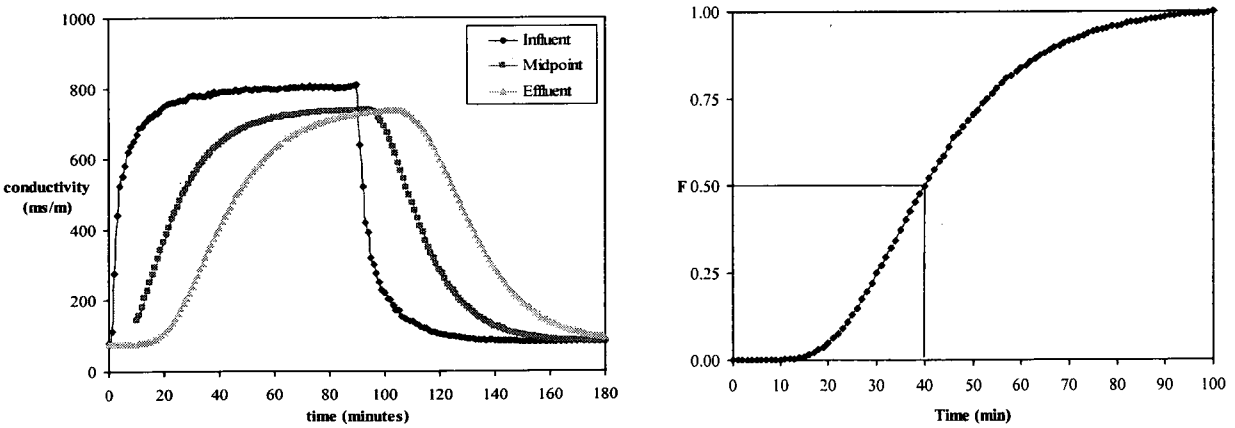

Figure 27 - Left: C-curves for the three sample points of the SIX installation run at 23.4 m3/hr with 32 rpm mixing frequency.
Right: Mean Residence Time (MRT) curve for the same trial.

As can be seen in *Figure 27* after the C-curves were generated from the conductivity measurements taken, the F-curve was created using the effluent C-curve and measured a MRT for this setting of 40.0 minutes. The theoretical HRT calculated by flow and volume for this trial was 46.4 minutes meaning there was a 14% difference in the values. This shows that there is some short-circuiting of the flow causing less consistent treatment then desired.

Figure 28 shows the reactors at this setting acted theoretically as 5 CSTRs in series. It should also be noted at this point that the salt solution was only fed for approximately twice the HRT (90 minutes) and as can be seen in the C-curves the effluent did not reach a steady state at all locations.

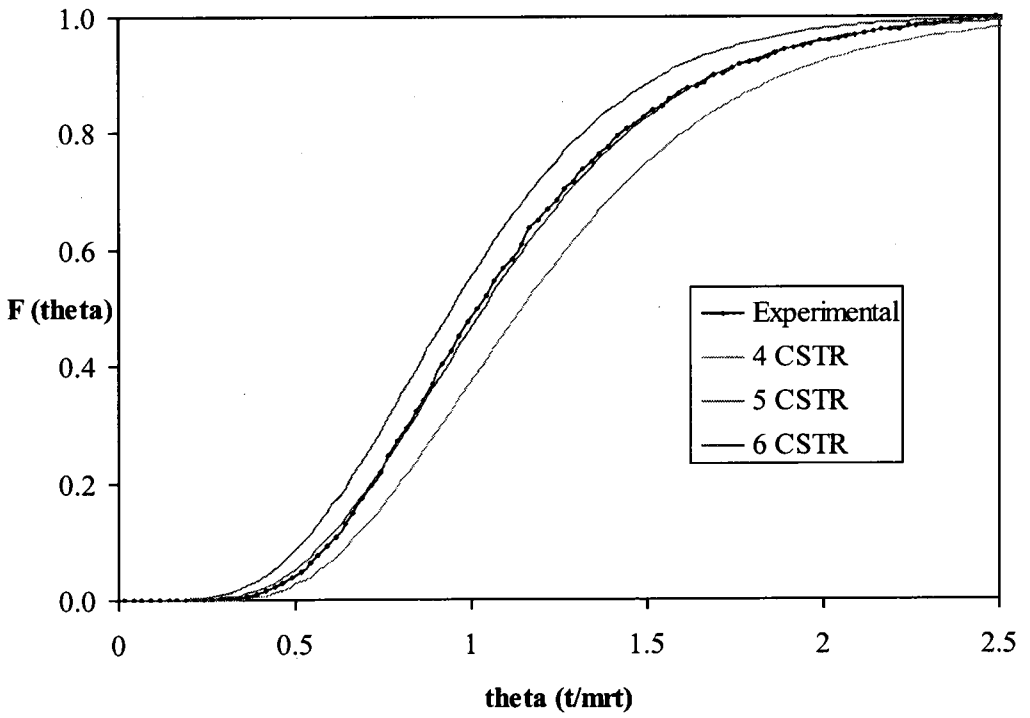

Figure 28 - F theta curves to compare experimental data to theoretical CSTRs in series for 23.4 m3/hr with 32 rpm mixing frequency.

It was concluded that the equilibrium point of the trial had likely been reached since the effluent readings did just begin to match the effluent readings (these readings were taken with the same instrument). The reason that the influent readings are higher is likely due to those measurements being taken with a different type of conductivity probe than the other two. This trend can be observed throughout all of the trials.

5.2.1.2 $52.4m^3/hr$ and 32 rpms - The second flow characteristic trial was conducted by doubling the flow of the pilot facility to approximately its maximum design flow at $52.4m^3/hr$. The mixing frequency of the paddles was left at 32rpm. This trial was performed to study the effect of flow variation on the pilot hydraulic characteristics.

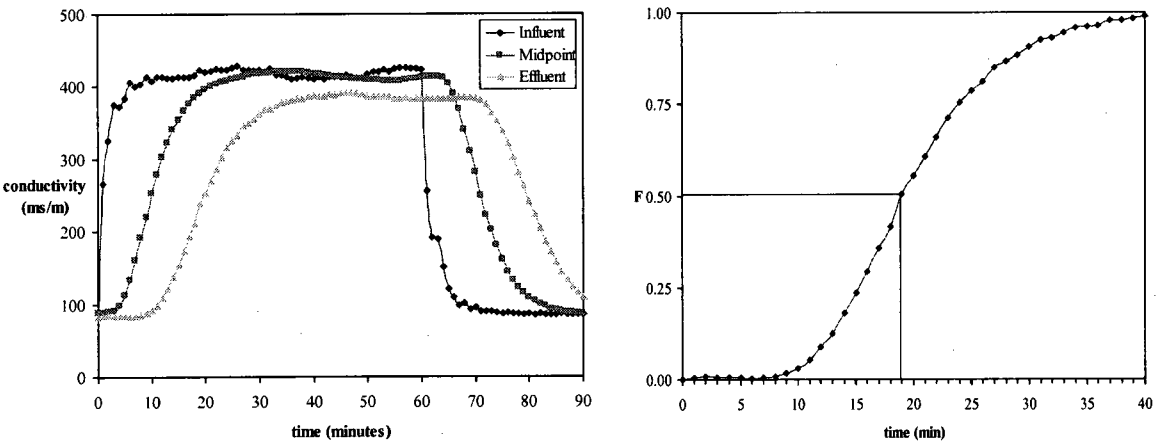

Figure 29 - Left: C-curves for the three sample points of the SIX installation run at 52.4 m3/hr with 32 rpm mixing frequency. Right: Mean Residence Time (MRT) curve for the same trial.

For these experiments the salt injection period was increased to three times the HRT instead of two. A clear steady state was reached providing reliable data. This data was used to generate the F-curve and find a MRT of 19.0 minutes, only 7% below the HRT estimate of 20.5 minutes. This illustrates that with increased flows, the hydraulic characteristics improve, assuming less short-circuiting and fewer dead-zones.

At higher flows the CSTRs in series increased from 5 to 8 confirming that the higher flows result in improved hydraulic characteristics and the ideal condition of plug-flow is approached as can be seen in *Figure 30.*

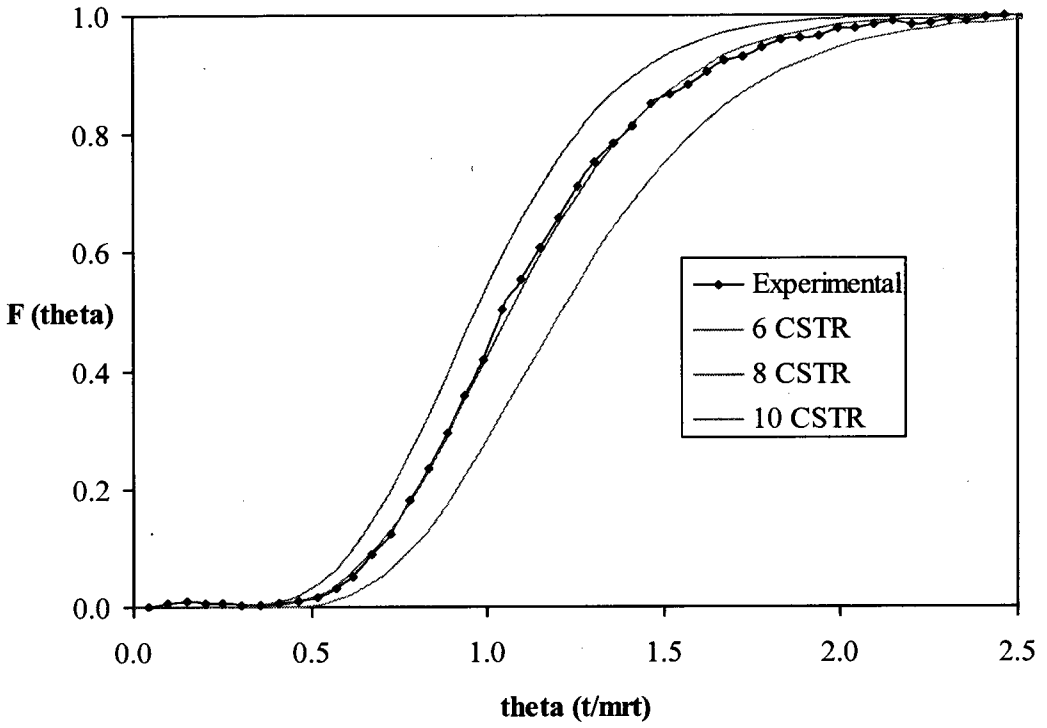

Figure 30 - F theta curves to compare experimental data to theoretical CSTRs in series for 52.4 m^3/hr with 32 rpm mixing frequency.

5.2.1.3 51.4m^3/hr and 45 rpm - The third trial conducted used the higher flow that showed the better flow characteristics and increased the mixing frequency of the paddles to study the effect of increased mixing energy.

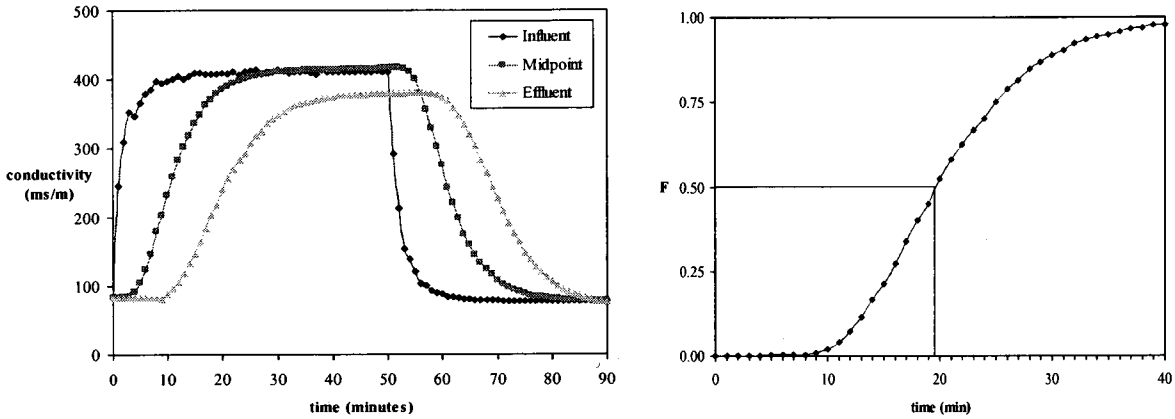

Figure 31 - Left: C-curves for the three sample points of the SIX installation run at 51.4 m3/hr with 45 rpm mixing frequency.
Right: Mean Residence Time (MRT) curve for the same trial.

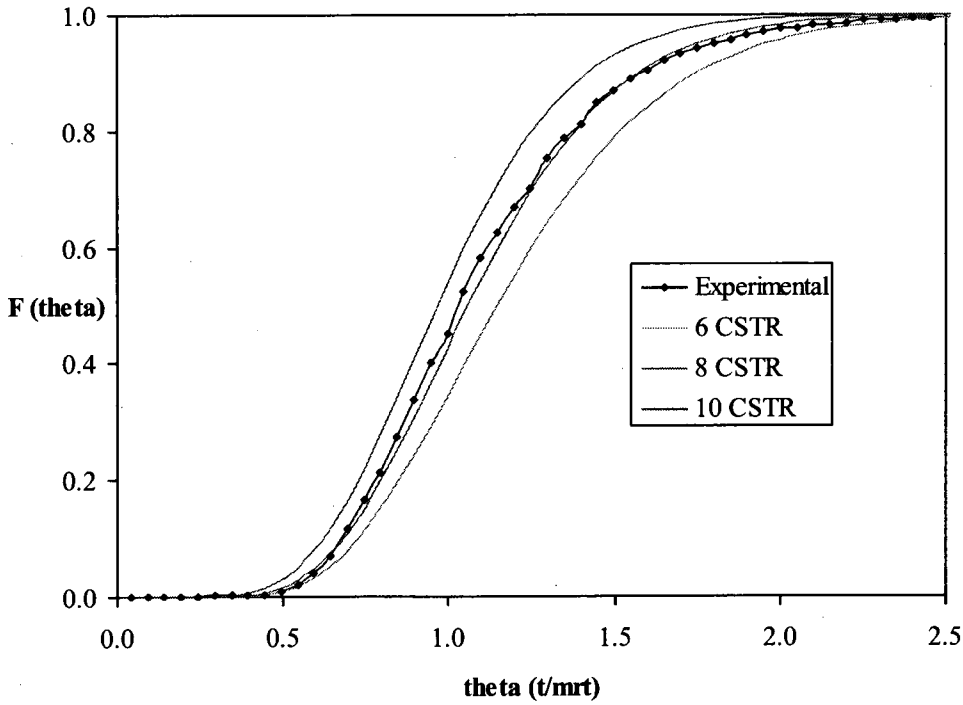

Figure 32 - F theta curves to compare experimental data to theoretical CSTRs in series for 52.4 m^3/hr with 32 rpm mixing frequency.

The plots indicate that with the higher mixing frequency the MRT increased slightly up to 19.7 minutes, decreasing the difference between the MRT and HRT to 5.7%. This is an insignificant increase compared to the trial with the slower mixing frequency. *Figure 32* shows that the CSTRs in series remained at 8 for both trials.

5.2.1.4 $52.4m^3/hr$ and 20 rpm - The fourth flow characteristic study was conducted with a flow of $52.4m^3/hr$ and a reduced mixing frequency of 20 rpm to study the effect of reduced mixing energy in the system on the hydraulic characteristics.

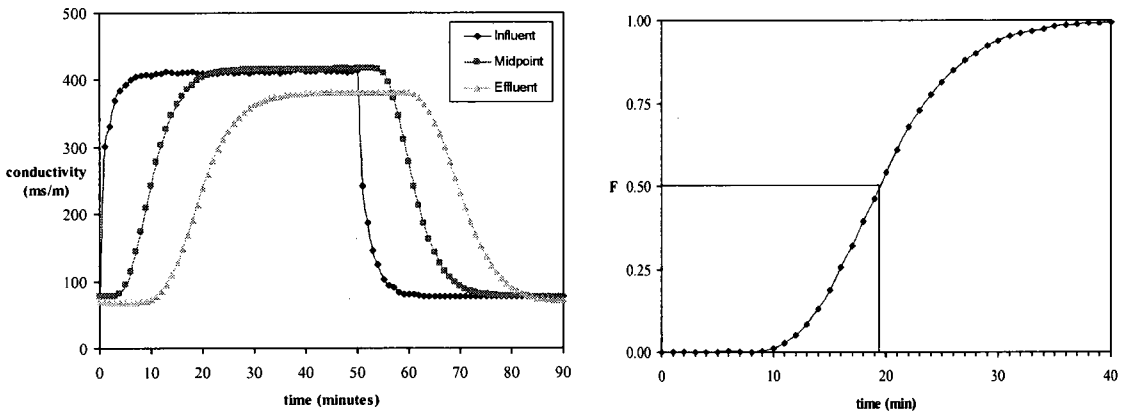

Figure 33 - Left: C-curves for the three sample points of the SIX installation run at 52.4 m3/hr with 20 rpm mixing frequency. Right: Mean Residence Time (MRT) curve for the same trial.

The reduced mixing speed had an insignificant effect on the residence times, reducing the difference to 4.9% with 19.5 minutes for the MRT compared to the 20.5 minutes of the HRT. The CSTRs in series changed significantly from 8 to 11 (*Figure 34*). This shows that reduced mixing frequency resulted in a substantial improvement to the hydraulic characteristics and made the pilot closer to the ideal plug flow condition.

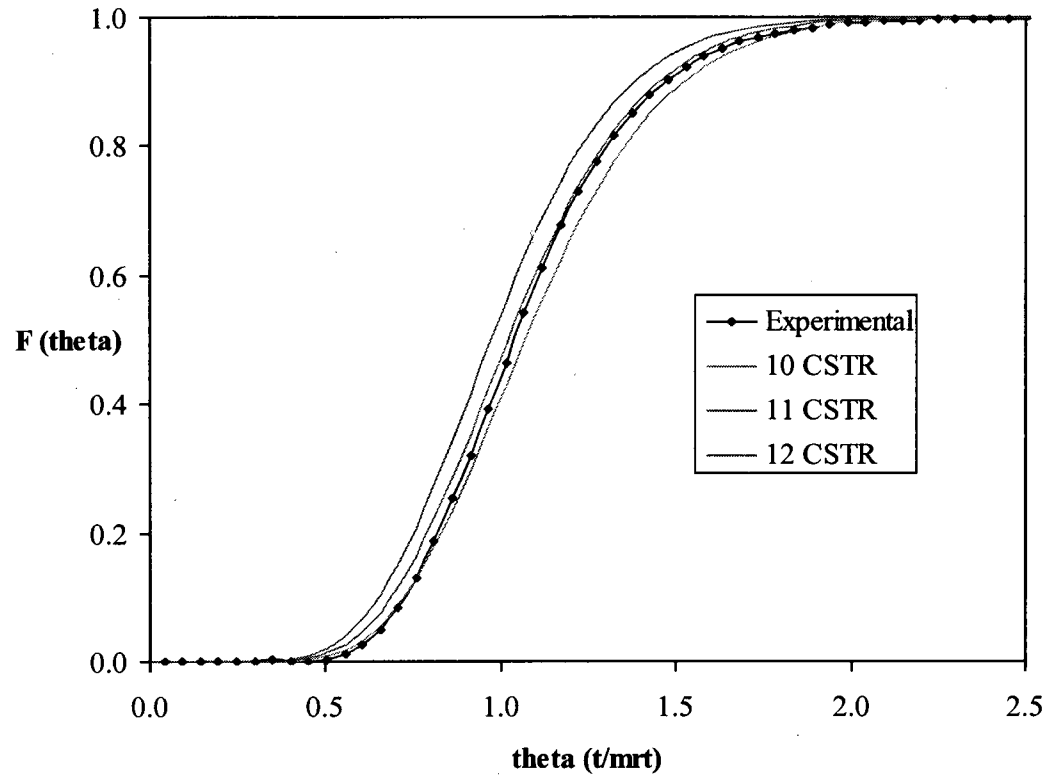

Figure 34 - F theta curves to compare experimental data to theoretical CSTRs in series for 52.4 m^3/hr with 20 rpm mixing frequency

5.2.2 Summary of Flow Characteristic Studies

The results from the four tracer trials are summarized in *Table 6*. The important figures are the lowest percent differences in HRT and the highest number of CSTRs in series. It was noticed from trial 1 to trial 2 that doubling the flow in the system nearly doubled the CSTRs in series and nearly halved the percent difference in the HRTs. This result shows that the higher flow rates yield much better flow characteristics than the low flow rates.

Once it was established that high flows yielded better results, the effect of rotation frequency was studied by adjusting the speed of the mixers. The last two trials were run

at the extremes to establish a relationship. As can be seen from the CSTR in series numbers, medium and high mixing frequencies show very similar characteristics, but the low frequency improved the overall flow characteristics of the system.

Table 6- Operating Parameters and Measured Values for Hydraulic Characteristic Studies with the Optimal Operating Condition Bolded.

Summary Table of the New SIX System Tracer Trials				
	Trial 1	Trial 2	Trial 3	**Trial 4**
Total Flow (m^3/hr)	23.4	52.4	51.4	**52.4**
RPM of Mixers (rev/min)	32	32	45	**20**
Volumetric HRT (min)	46.4	20.5	20.9	**20.5**
Experimental HRT (min)	40.0	19.0	19.7	**19.5**
Percent Difference (%)	14%	7.3%	5.7%	**4.9%**
CSTRs in Series (N)	5	8	8	**11**

It can therefore be stated that the most hydraulically effective method for running the pilot facility is at the higher flows of around 50m^3/hr with the low mixing frequency of 20 rpm. This section answers the fourth research question of what are the optimal hydraulic operating conditions of the SIX contactors.

It should be noted that study focused on the hydraulic characteristics. Adsorption efficiency was not part of this study and does not necessarily correlate to the determined optimal hydraulic conditions. Further studies in this area are required.

5.2.3 Pilot Efficiency Tests of the Optimized Flow Characteristics

For the two optimal hydraulic process conditions the adsorption characteristics in the pilot were studied. The pilot was adjusted to the two different extreme mixing conditions of 20rpm and 45rpm. UVT_{254} analysis as a surrogate for DOC concentration was performed as an indicator of pilot efficiency.

The results from the two trials are presented in *Table 7*. The table shows a fairly linear progression of the improved UVT_{254} (and therefore decreased DOC concentration) as the water travels through the treatment process. There are however a few anomalies that do not follow the overall pattern. These numbers are far more likely due to contamination of the samples with particles reducing the UVT_{254} and do not suggest an increase in DOC from rapid resin desorption in the middle of the treatment process.

*Table 7 - Data in UVT254 from the first Mixing Trials with the **anomalies bolded**.*

Trial 1: 14mL/L resin concentration with 20 rpm										
Time Treated (min)	0.0	1.1	3.7	6.3	8.9	11.5	14.1	16.8	19.4	20.4
Sample 1 (UVT_{254})	74.5	76.0	77.9	**74.9**	79.5	85.0	87.2	87.4	91.4	**90.0**
Sample 2 (UVT_{254})	75.3	76.0	78.0	78.8	80.0	85.7	89.3	**85.8**	91.0	91.9
Trial 2: 16mL/L resin concentration with 45 rpm										
Time Treated (min)	0.0	1.1	3.7	6.3	8.9	11.5	14.1	16.8	19.4	20.4
Sample 1 (UVT_{254})	76.3	78.8	80.2	81.3	82.4	88.0	90.3	92.8	93.5	**88.7**
Sample 2 (UVT_{254})	77.3	79.2	80.2	81.8	82.6	87.6	90.0	91.4	93.0	93.6

Even with the anomalies, the trend in both experiments follow each other well without one sampling time favoring heavily over the other (*Figure 35*). This indicates that the system had reached equilibrium and that the two sampling times can be used as duplicates.

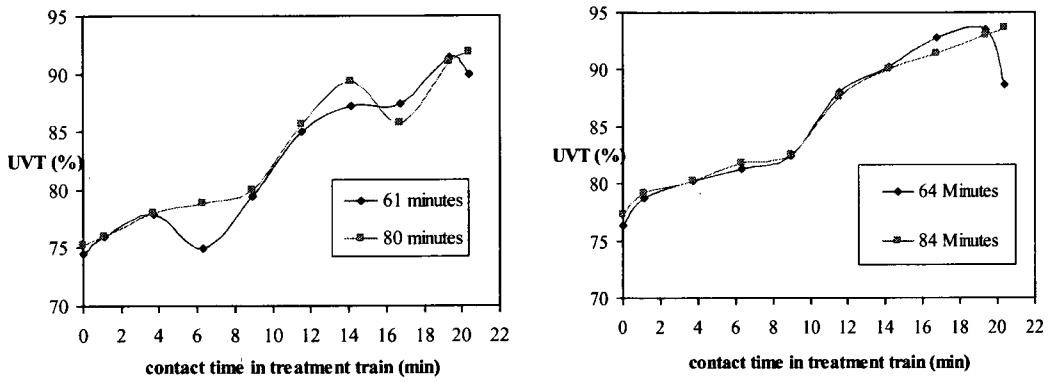

Figure 35 - The repetitions at the two times for the optimized pilot efficiency trials for 20rpm with 14ppm of resin (left) and 45rpm with 16ppm of resin (right).

The resin concentrations were not the same and the UVT values were corrected to compare the two mixing frequencies. This correction is small according to models previously developed at PWN. An increase from 14mL/L to 16mL/L with the Lewatit® resin only increases UVT_{254} by approximately 1%.

After correcting for concentrations, ignoring anomalies and duplicate averaging (*Figure 36),* it can be concluded that both treatments result in comparable adsorption efficiencies. Despite the improved hydraulic characteristics at the slow mixing frequency, the effluent quality is not effected and therefore not important in the overall treatment process. The relevance of these results may be in the design economics for energy and operation and maintenance of the motors. This answers research question five as to whether optimal hydraulic conditions yield better adsorption characteristics.

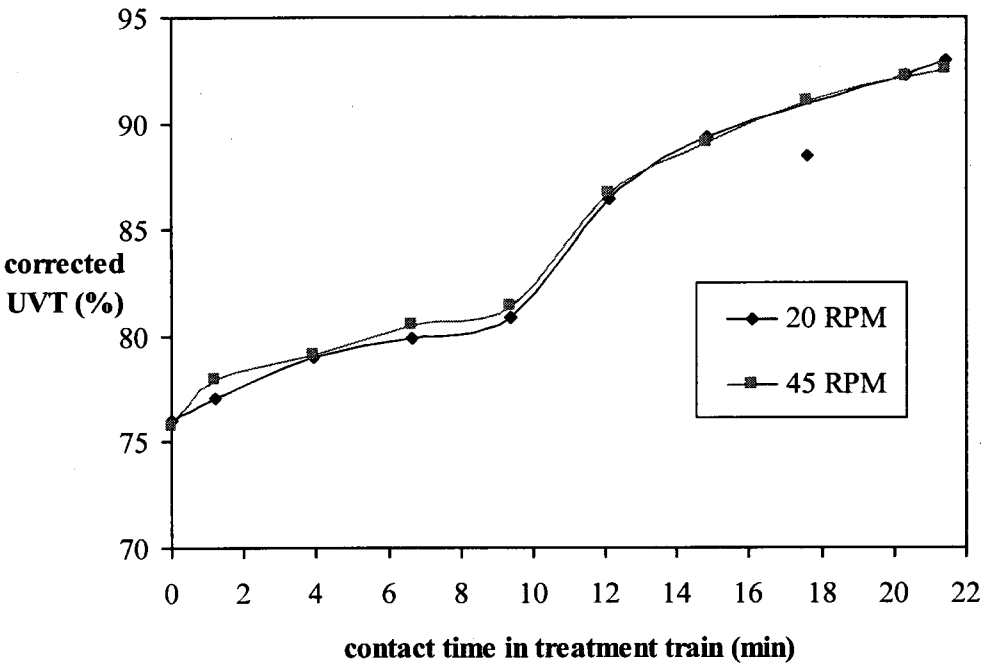

Figure 36 - Comparing the Effect of Mixing Speed on UVT (%) correcting for resin concentration with the extraneous values not included in the line.

5.3 Nanofiltration and Reverse Osmosis of Spent Regeneration Solution for Reuse

In the desire to reduce the waste stream from the ion exchange regeneration and reuse the remaining salt, organics removal with nanofiltration and salt concentration with reverse osmosis has been proposed to create a cyclic ion exchange process.

5.3.1 Nanofiltration for DOC Removal

For the nanofiltration trials there are three major parameters that need to be evaluated to determine whether it is a feasible option for treating the used regeneration

stream. These three parameters are DOC retention by the membranes, sodium chloride salt passage through the membranes, and irreversible fouling potential of the membranes from pore clogging due to organic build up and precipitation. For all of the trials the NF unit will be run as close to 80% efficiency as possible. This means that 80% of the feed volume will be converted to permeate while 20% of the feed volume will be converted to concentrate.

5.3.1.1 DOC Retention and Salt Passage Efficiencies - There are two important parameters that need to be evaluated to check the efficiency of the nanofiltration trials with the denitrification effluent. The first parameter is the retention percentages of DOC (which should be high). The second parameter is the retention percentages for sodium chloride salt (which should be low). *Table 8* shows results for DOC and salinity, analyzed by the external laboratory HWL averaged over the 9 days of sampling (~180 hours of operation).

Table 8 – Averaged data over 180 hours of NF operation analyzed by HWL with the membrane retention percentages bolded.

		Feed	Permeate	Concentrate	**Percent Retention**
DOC mg/l	Avg.	639	177	737	**72.4%**
	St.Dev.	49	27	91	
Salt as g/l NaCl	Avg.	62.7	44.9	48.7	**28.5%**
	St.Dev.	5.7	6.5	3.7	

The table shows that the DOC retention is lower than expected at 72% efficiency where the literature stated greater than 95% . The salt retention is higher than expected at almost 29% where the literature stated less than 5%. The high salt retention issue will be addressed first.

It was noticed during the trial operations that the salt concentration for the permeate and the concentrate were both lower than in the feed. The salt wasn't accumulating in the system anywhere causing the high retention readings, rather it was being lost. It was thought that maybe during the flushing process with the drinking water that the recirculation stream was being diluted and the salt lost to the drainage of the flush waters. To test this hypothesis, a Hach HQ 40d Multimeter® recorded the permeate conductivity every minute over a few flushing cycles (*Figure 37*).

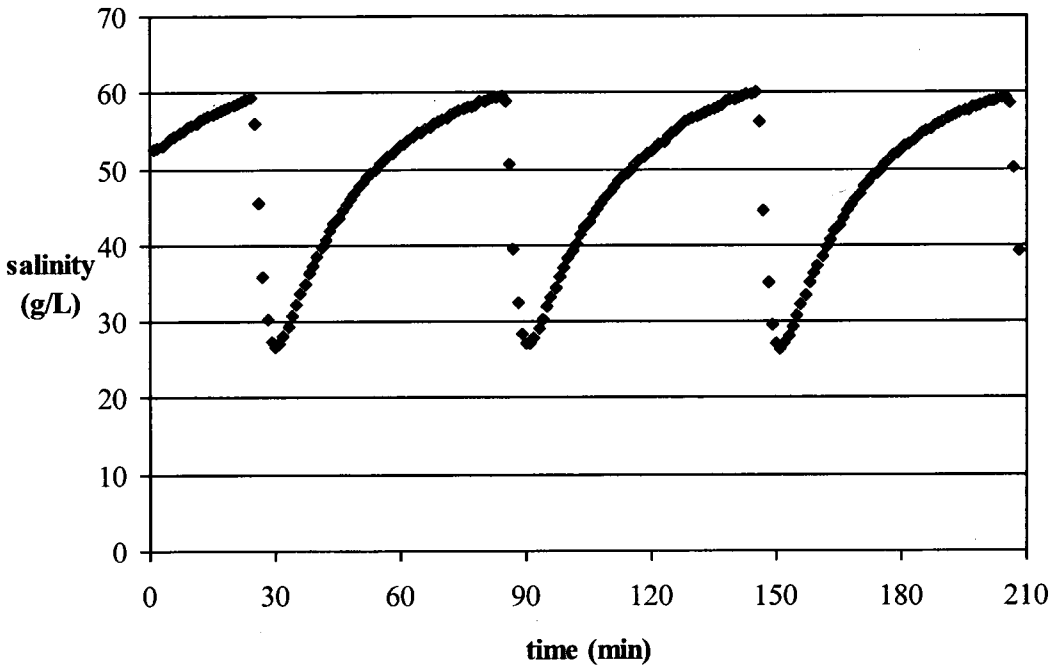

Figure 37 – Permeate salinity during three flushing cycles of the NF trials.

The permeate flushing study showed that the drinking water flush was indeed diluting the permeate. It was calculated that the flush was reducing the average permeate salinity by 18% every flush from that day's influent level 59.1g/L to the average salinity of 48.8g/L found over the three flushes. The trial agrees well with the average measured that day of 44.9 g/L showing the process to be fairly constant. The flush then was diluting

all of the permeate and concentrate data. The corrected levels with the dilution accounted for can be seen in *Table 9*.

Table 9 – Averaged data over 180 hours of NF operation analyzed by HWL with the modified retention percentages data accounting for dilution bolded.

		Feed	Permeate (18% increase)	Concentrate	Dilution Correction Percent Retention
DOC mg/l	Avg.	639	**209**	737	**67.4%**
	St.Dev.	49	27	91	
Salt as g/l NaCl	Avg.	63	**53**	49	**15.6%**
	St.Dev.	5.7	6.5	3.7	

Even with this correction for dilution, the salt rejection (16%) is still higher than expected (5%). This may be due to the high organic loading on the surface temporarily fouling the membrane. As noted in the literature, fouling increases salt rejection.

Table 9 shows that with the dilution correction, the NF installation exhibits 67% retention of the DOC, even lower than before. The installation is not running as efficiently as stated possible in the manufacturer specifications of greater than 95%. There is likely a problem with the NF pilot itself or the membrane performance with the high organic, high salt loading. Either the installation needs to be adjusted, the membranes changed, or the amount of DOC reaching the nanofiltration unit reduced.

To determine why this low retention occurs, NOM scans have been studied to see what fraction of the DOC is passing through the membrane. The scans are in APPENDIX F.

Table 10 – Summary of the two NOM scans performed during NF trials with all data presented as a percent of the total organic concentration with key values bolded.

8-7-2009	Dissolved Organic Carbon	Humic Substances (MW>300)	Organic Acids (MW<300)
Feed	93.2%	45.4%	28.9%
Permeate	90.7%	**3.0%**	**75.9%**
Concentrate	93.9%	53.6%	19.0%
15-7-2009	Dissolved Organic Carbon	Humic Substances (MW>300)	Organic Acids (MW<300)
Feed	94.2%	36.0%	28.8%
Permeate	78.8%	**<1.0%**	**68.7%**
Concentrate	95.7%	52.2%	21.9%

The summary of the NOM scans in *Table 10* shows that the humic substances (the larger compounds) are being highly rejected while the smaller organic acids are not. The organic acids should also be highly rejected at the operating pH.

During the DNF process, acetic acid is being dosed into the biological fixed media filters as an assimilable carbon source and a pH control. The dosing is between 200mg/L and 400mg/L with only 50mg/L to 75mg/L of this needed as the assimilable carbon source. A further study of the NOM scan from July 15th (details in APPENDIX F) show this acid dosing to be the only source of acid to the nanofiltration unit. There is a negligible amount in the regeneration stream coming from the resin regeneration in the ion exchange. This can be seen summarized in *Table 11*.

Table 11– Summary of the acid fraction of DOC traveling through the regeneration reuse progress on July 15th.

	IX Regen Waste	DNF with Acid Dose	DNF Effluent	NF Influent	NF Permeate
DOC mg/L	310	592	535	646	155
Acids mg/L	0.01	243	205	197	135
%DOC that are Acids	0.0%	41%	38%	31%	87%

All of the acid found in the system (*Table 11*) arises from the dosing for the DNF. It also shows that the majority of the DOC in the permeate of the nanofiltration unit

(87%) is composed of acid. By using another source of acid for balancing pH and using only the needed amount of acetic acid, the inefficiency problem with the NF unit can be solved.

This correction would mean for the July 15th data only injecting ~40mg/L acetic acid. This would reduce the NF permeate DOC concentration from 155mg/L to around 20mg/L by eliminating the acid source. The results would be an increase in the NF pilot DOC removal efficiency from the low 67% to a more expected value of 97%. This answers part 6 of the research questions section as to the DOC retention and salt passage capabilities of the membranes and pilot.

5.3.1.2 Precipitation Fouling - One potential fouling agent explored for the NF trials was the formation of precipitants due to the ion concentrations in the resin regeneration solution. Basic K_{sp} calculations were made to compare figures found on the chemistry department's website at the University of Alabama in Hunstville (www.chemistry.uah.edu). These calculations are made using the equations found in the literature review section 3.3.3.

Table 12– Results from K_{sp} calculations performed for NF membrane trials with potential precipitants highlighted and flagged.

Compound	Ksp	Solubility Product	x5 Solubility Product	Flag (if SP>Ksp)
$BaCO_3$	8.10E-09	0	0	
$CaCO_3$	3.80E-09	0	0	
$FeCO_3$	3.50E-11	0	0	
$MgCO_3$	4.00E-05	0	0	
$MnCO_3$	1.80E-11	0	0	
$Ca(OH)_2$	7.90E-06	6.47E-16	3.23E-15	
$Fe(OH)_2$	7.90E-15	2.67E-17	1.34E-16	
$Mg(OH)_2$	1.50E-11	6.83E-16	3.42E-15	
$Mn(OH)_2$	4.60E-14	3.37E-18	1.68E-17	
$Ba_3(PO_4)_2$	1.30E-29	1.19E-27	3.72E-24	!!
$Ca_3(PO_4)_2$	1.00E-25	5.81E-18	1.82E-14	!!
$BaSO_4$	1.10E-10	3.29E-08	8.24E-07	!!
$CaSO_4$	2.40E-05	5.59E-05	1.40E-03	!!

Barium and calcium cations combined with the phosphate and sulfate anions show a potential for precipitation (*Table 12*). Yet other than the $CaSO_4$ these compounds should be precipitating out in the feed solution and settling out of the system before reaching the NF. Since K_{sp} calculations are performed in ideal matrices and even then the literature varies on exact values, it is likely that the complexity of the solution with its high salt and DOC concentrations is allowing higher concentrations of these ions to pass through the membranes than is typical. Therefore the ion concentration data from the 180 hours of operation should be observed to check for the potential of build up.

Table 13 – Ion removal percentages from denitrification effluent by nanofiltration

Component		Feed	Permeate	Concentrate	Percent Retention	Dilution Correction Percent Retention (18% increase of permeate)
Barium µg/l	Avg.	22.0	14.8	29.8	32.6%	20.5%
	St.Dev.	3.8	4.0	3.6		
Calcium mg/l	Avg.	14.4	13.7	21.8	5.1%	-12.0%
	St.Dev.	1.3	1.0	0.7		
Sulphate as mg/l SO_4	Avg.	6480	308	8912	95.2%	94.4%
	St.Dev.	792	198	649		
Phosphate as mg/L PO_4	Avg.	6.2	0.7	6.0	89.0%	87.1%
	St.Dev.	2.5	0.2	1.6		
Nitrate as mg/l NO_3	Avg.	7.8	2.2	0.7	71.1%	66.0%
	St.Dev.	6.3	2.4	0.5		

The NF membranes used in these experiments have low rejection levels of calcium and barium (*Table 13*) meaning that precipitation on the membranes is not likely. Without these two ions increasing in concentration and therefore increasing their solubility products (K_{sp} values), solids formation cannot occur that hasn't already. Long

term pressure drop trials are still necessary to ensure there are no precipitation fouling issues.

The membranes perform well for low level nitrate removal and high level sulfate and phosphate removal. This makes the membrane filtration useful after the denitrification step as a nitrate polishing step and as a general ion reduction step. This will help from these ions accumulating in the regeneration process over time as the solution is reused and will help keep the necessary concentration gradients high.

5.3.1.3 Irreversible Fouling Potential over Time - The following trials were run to determine the flushing duration and frequency needed to allow for constant runs. The forward flushing method for the NF installation is a mixture of drinking water flowing at $12m^3/hr$ and compressed air at a pressure of 6.0 bar.

Two short term studies (2 to 3 hours) were conducted to determine potential pressure drop decreases with a few different flushing regimes. In *Figure 38* it can be observed that the pressure drop returned to its starting levels between 2.0 and 2.5 bar with 30 second flushes after 30 minutes and after 45 minutes. Even with longer frequencies, up to 60 minutes, the pressure drop returned to between 2.0 and 2.5 bar after every flush. This shows that the system has the potential to be operated with 30 second flushes every one hour without immediate problems arising. Also the temperature appears stable at these settings (APPENDIX F). These settings have been adopted in the multiple day study.

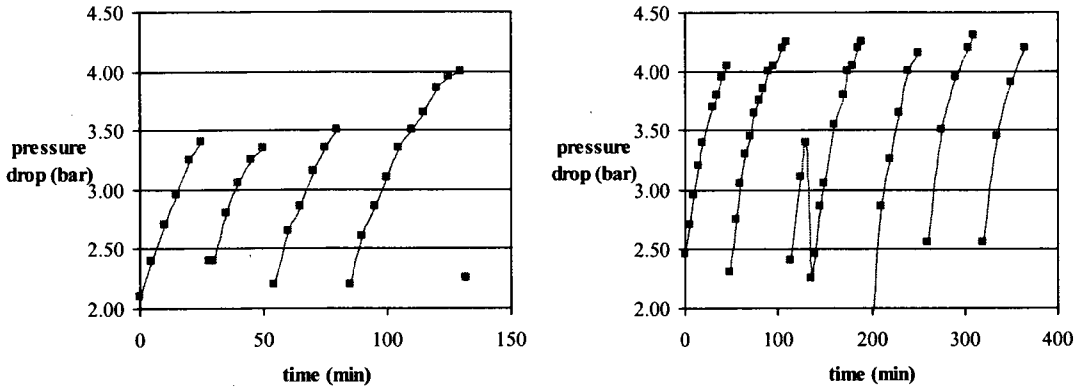

Figure 38 – Left: Flushing trials with 30 sec. duration and 30 to 45 min. frequencies Right: Flushing trials with 30 second duration and 45 to 60 minute frequencies.

The next test then is to determine the irreversible fouling potential over a longer period of a week from potential organic build-up or precipitant fouling. *Figure 39* shows the pressure drop over the membrane of the initial trials conducted (*Figure 38 - Right*) to determine flush frequency and the pressure drop over the membranes after ~180 hours of intermittent operation with the longest continuous stretch being 96 hours. The only cleaning of the membranes during this time was a forward flush of clean drinking water mixed with compressed air every hour for 30 seconds.

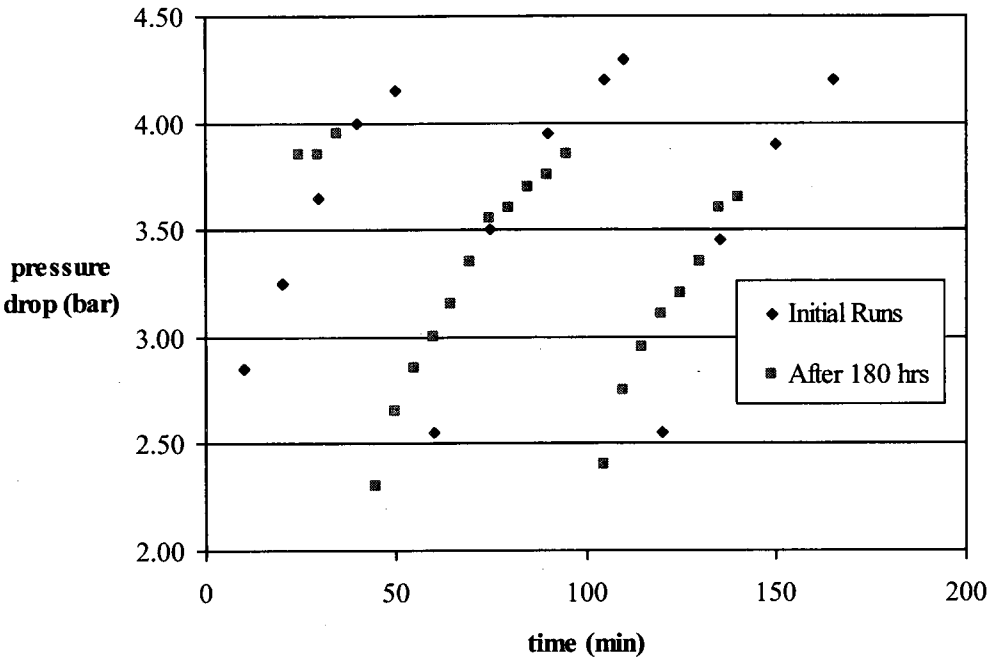

Figure 39 – Comparing the pressure drop during operation of the NF unit to remove DOC at the beginning of the trials and after ~180 hours

The initial trial and the trial after 180 hours show no apparent difference (*Figure 39*). The pressure drop increased 1.5 to 2.0 bars per hour and returned to between 2.0 and 2.5 bars after every flush. This indicates that there was no apparent irreversible fouling occurring over the trial period. In this study the spiral wound NF membranes have the potential to be run for extended cycles with no extra cleaning agents or methods required. This answers part 7 of the research questions regarding the irreversible fouling potential of the nanofiltration unit with the regeneration waste stream.

5.3.2 Reverse Osmosis for Salt Concentration

The current concept of the cyclic operation reuse process foresees an RO concentration step. Operational pilot data, as presented in *Figure 40* shows the salt mass

balance, indicating that there may be limited added value for the RO. This section regards part 8 of the research questions by showing that there is no need for the RO in the current pilot configuration.

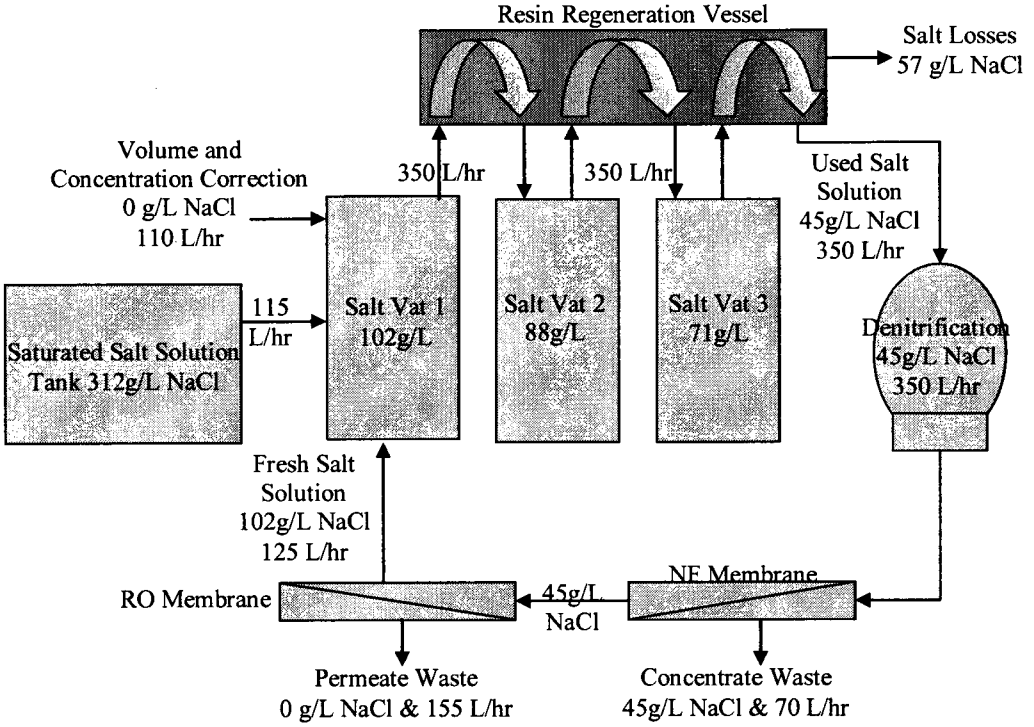

Figure 40 - The schematic and current mass balance figures for a concentration step of the salt in the used salt solution regeneration using RO membranes.

The RO concentration step would allow for the direct reuse of the salt but in much lower volumes and would therefore still need to be supplemented with the same amount of new salt as the un-concentrated salt solution. It would actually lower the salt mass slightly with the less than 100% salt rejection efficiency of the standard RO membranes.

For the concept without RO, it must be addressed if the return flow has a low enough volume or a high enough concentration to be directly supplemented with the saturated salt solution. A mass balance with iterations (*Table 14*) shows how a cyclic reuse will affect the salt concentrations over time. The concentration of salt in the first

tank is now dependent on the concentration of the return levels. The formula used for these calculations can be seen in *Equation 13*.

Table 14- Lower and Upper Limits with Iterations on New Proposal

Upper Limit Iterations			Lower Limit Iterations		
It. No.	Salt Vessel 1 Concentration (g/L)	Regenerated Salt Concentration (g/L)	It. No.	Salt Vessel 1 Concentration (g/L)	Regenerated Salt Concentration (g/L)
0	102.4	47.4	0	102.4	47.4
1	98.1	45.4	1	38.0	17.6
2	96.5	44.7	2	14.2	6.6
3	95.9	44.4	3	5.3	2.5
4	95.7	44.3	4	2.1	0.9
5	95.7	44.3	5	0.8	0.4
6	95.6	44.3	6	0.4	0.2
7	95.6	44.3	7	0.2	0.1
8	95.6	44.3	8	0.2	0.1

$$C_{SV} = \frac{Q_{NF} \cdot C_{NF} + Q_{SS} \cdot C_{SS}}{Q_{SV}} \qquad \textit{Equation 13}$$

Where: C_{SV} = Salt Concentration in the First Salt Vessel (g/L)
Q_{SV} = Flow from the First Salt Vessel (L/hr)
C_{NF} = Salt Concentration of the NF effluent (g/L)
Q_{NF} = Flow of the NF effluent (L/hr)
C_{SS} = Salt Concentration in the Saturated Salt Solution Tank (g/L)
Q_{SS} = Flow from the Saturated Salt Solution Tank (L/hr)

One assumption for these calculations was that the flows would be at the future proposed levels of 350L/hr total flow into the denitrification system. Also it was assumed that there was no salt loss through the membranes and that the membranes operated at 80% efficiency in terms of flows. The treated salt solution concentration used was at the level of the NF effluent being flushed with drinking water (44 g/L).

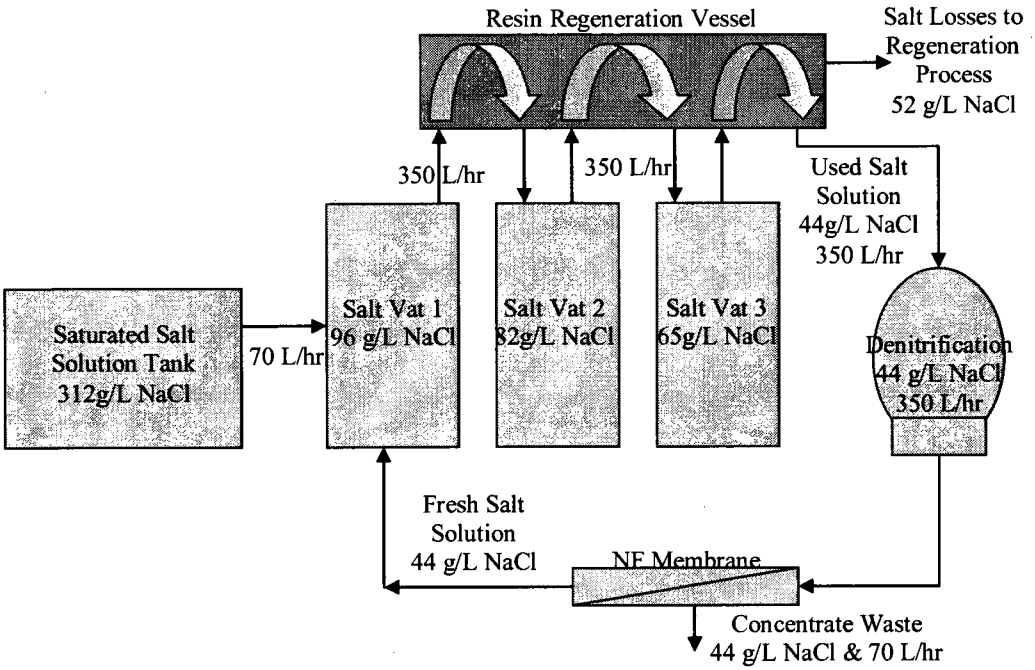

Figure 41 - New proposal for reuse of the fresh salt solution without a concentration step involving an RO membrane.

An alternative proposal would be to feed the freshly cleaned salt solution directly back into salt vessel 1 while supplementing the remainder with the concentrated solution. This would avoid a high energy demand step of the RO and reduce further mass losses of the salt through the less than 100% efficiency of RO membranes.

In case an alternative resin that requires a higher salt concentration is selected, adjusting the efficiency of the NF can compensate for this. For example reducing the NF efficiency from 80% to 70% can result in an increase in the salt concentration of the feed tank from 102 g/L to 134 g/L (a 24% increase in concentration, see APPENDIX G for detailed calculations).

As noted before the salt concentrations used in the calculations are approximately the values found after the clean water flush of the NF. If the drinking water flush is eliminated, the salt concentrations remain higher, and the process would be more

efficient. With the 18% increase in salt concentration found during the NF dilution study (section 5.3.1.1), the concentration could be increased up to 109g/L.

Ultimately there are multiple options with this installation. Currently the process can produce the required salt concentration to meet the ion exchange resin regeneration demand. In a case where more salt is required, the dilution hasn't been solved, and the 80% is still desired, then a concentration step may be required.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The research conducted in this report focused on three primary steps of the Suspended Ion eXchange (SIX) process developed by PWN. The first step focused on the resin regeneration procedure, the second step focused on the resin tank contactors, and the third step focused on the used resin regeneration solution reuse.

The objectives of the experiments performed were to determine the best available operating conditions of the ion exchange process at PWN in terms of hydraulics and resin regeneration. Also, it was desired to see if the ion exchange process could become cyclic by adding a regeneration fluid treatment and recycling process.

6.1 Conclusions

6.1.1 Resin Regeneration

The regeneration desorption kinetics of the Lewatit® resin used in the ion exchange process at PWN has not previously been measured. Desorption models needed to be generated to predict the optimal operating conditions of the regeneration process within the current physical restrictions of the pilot. The desorption kinetics were done on the bench scale, modeled, and verified with pilot studies.

From the jar test experiments it was determined that the regeneration efficiencies of the various salt solutions could be predicted and used to model the pilot. Pilot studies were done that support this data. The one issue with the model is that it cannot account for the counter-current method and therefore will slightly under predict the actual regeneration efficiencies.

Using this model it was determined that slightly higher regeneration efficiencies could be achieved by eliminating the twice used salt solution and increasing the contact times of the other two salt solutions (*Table 4*). The major advantage of this is the simplification of the process.

6.1.2 Hydraulic Characteristic Studies

The resin tank contactor research was conducted to gain a better understanding of the hydraulic characteristics of the SIX contact tanks. This was done by modeling tracer studies at the extreme process conditions for the pilot facility: two flows (20 m^3/hr and 50 m^3/hr) and three mixing frequencies (20 rpm, 32 rpm, and 45 rpm).

It was determined that the new design of the SIX resin contact tanks had the best flow characteristics at high flows and low mixing speeds. Under these conditions the pilot behaved as 11 CSTRs in series with a difference between the theoretical hydraulic residence time and actual mean residence time of less than 5%. The higher flows show increased efficiency over the lower flows in both categories.

In pilot scale experiments it was observed that the differences in removal efficiencies for 11 and 8 CSTRs in series were not significantly different. The number of

CSTRs in series reflects the mixing speeds used. Therefore, the pilot can be run at high flows in combination with any mixing frequency.

6.1.3 Treating the Regeneration Solution for Reuse

Regeneration of the resin in the ion exchange process at PWN requires a high concentration of salt resulting in a high consumption. To reduce this consumption a feasibility study was conducted to see if the waste regeneration stream could be treated and then reused. This reuse step is known as cyclic operational ion exchange. For PWN cyclic operation consists of biological denitrification followed by nanofiltration (this research).

6.1.3.1 DOC Removal and Salt Retention with Nanofiltration - Nanofiltration had lower than expected DOC removal from the reuse stream (67%). It was found that the membranes were allowing primarily organic acids through. To enhance the biological denitrification and for pH correction, acetic acid was being dosed. It is assumed from following the organic acid concentrations through the treatment processes that the acetic acid is responsible for the low DOC rejection. If the acetic acid dose used to control pH is replaced with another acid such as HCl, then the DOC rejection efficiency theoretical would increase (97%).

For the cyclic operation, it is desired to have low salt rejection rates in the reuse treatment process. It was observed in the nanofiltration trials that the salt rejection was 16% (corrected for dilution in NF pilot).

The membranes did not exhibit irreversible fouling over 180 hours and showed the potential to run for extended periods of time with only a basic flushing procedure combining drinking water with air.

The DOC retention, the salt passage, and the fouling behavior of the nanofiltration indicate that the application of this technology is feasible in cyclic operation but still needs to be optimized.

6.1.3.2 Concentrating the Diluted Salt Solution - In the original concept of cyclic operation, application of RO to concentrate the NF permeate was foreseen. Mass balance calculations on the salt concentrations based on the NF studies showed through the cyclic operation processes that RO concentration can be eliminated.

It has been determined that the salt concentration could run up to approximately 100 g/L at 80% efficiency of the NF pilot, allowing for the current regeneration system to be used. These numbers do not account for the operational constraints of the NF and higher concentrations could be reached.

The RO step that has been proposed to concentrate the NF effluent salt has been realized to be currently unnecessary. The treated salt solution can be directly supplemented with the saturated salt solution removing the energy intensive concentrating step and further simplifying the process.

6.2 Recommendations for Future Operations

6.2.1 Tracer Studies

It is suggested then that the pilot is run at the high flows of 50m^3/hr to meet demand and at the low mixing speeds of 20rpm to save on energy costs and wear and tear on the mixing motors.

6.2.2 Resin Regeneration

It is suggested to eliminate the third salt regeneration solution and increase the contact time of the other two salt solutions from 4 minutes for all three with 21 minutes of total rinse time to 10 minutes for the first salt solution and 9 minutes for the second salt solution with 14 minutes of total rinse time.

6.2.3 Treatment of the Regeneration Solution for Reuse

6.2.3.1 DOC Removal and Salt Retention with Nanofiltration - It is suggested to use the NF for DOC separation, but changing the pH adjustment chemical from acetic acid to hydrochloric acid and the microbial carbon source from acetic acid to a larger molecule such as glucose to reduce the DOC passage through the membrane.

6.2.3.2 Concentrating the Diluted Salt Solution - It is suggested to not use a concentration step with the current resin and run the pilot at 80% efficiency or edit the process to reduce dilution during the nanofiltration flush. More research can still be done in the area of RO concentration if the resin in the ion exchange process is changed resulting in higher salt concentrations required.

6.3 Recommendations for Future Research

6.3.1 Tracer Studies

It is suggested for future research that tracer studies be conducted with particle tracers (such as phosphorescent particles) instead of dissolved tracers (such as salt). Particles behave differently in a fluid than dissolved constituents. To accurately model the resin beads, which are discrete particles and do not dissolve in the system, different tracers need to be used and similar studies should be conducted.

6.3.2 Resin Regeneration

Recommended research in this area is to study alternative regeneration methods such as using a fixed bed pull through regeneration of the resin as opposed to the completely stirred method to see if changes in regeneration efficiency can be observed.

6.3.3 Treatment of the Regeneration Solution for Reuse

6.3.3.1 DOC Removal and Salt Retention with Nanofiltration - It is suggested to use the NF for DOC separation but make adaptations to the existing design and test these before continued use. These suggestions are:

- Replace the drinking water of the flush with permeate solution as to not dilute down the recirculation stream.
- Retain the flush permeate water in the feed tank and allow it to run through the NF again reducing salt losses from the flush waste.
- Replace the acetic acid dose in the DNF step with an alternative acid to increase the NF DOC rejection efficiency.

- Change the valve placement of the flush process so that only the membranes are flushed, not the entire NF pilot.
- Replace the permeate manual valve with an automated valve to allow for more consistent permeate flow and therefore predictable efficiency.
- Replace the air injection system from a single point pipe injection into air diffusers in the pressure vessels to ensure proper air mixing.
- Optimize the air pressure system for various pressures and flows.

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APPENDICES

APPENDIX A

PILOT FACILITY SPECIFICATIONS

SIX Pilot Specifications for Volume and Hydraulic Residence Times

Two Flow Regimes		
Low Flow (m^3/hr)	20	
High Flow (m^3/hr)	50	
Reactor Volumes (m^3)		
Piping to Tank	0,15	
Tank 1	8,82	
Tank 2	8,75	
Intermediary Piping	0,03	
Volume after Tank 1	8,97	
Total Volume	**17,75**	
Hydraulic Residence Times	2 reactors (hr)	2 reactors (min)
Low Flow	0,89	53,3
High Flow	0,36	21,3
Concentrations and Conductivities Constants		
Approx. Background Conductivity (ms/m)	80	
Desired Minimum Conductivity (ms/m)	400	
Mimimum Concentration Required (approx. g/L)	2	

Denitrification Specifications on UltraBead® Filters from www.ultrabead.com

MODELS, PRICES AND TECHNICAL SPECIFICATIONS

MODEL	HEIGHT X DIAMETER	POND CAPACITY	MAX. FISH LOAD	FOOD PER DAY	MEDIA (BEADS)	PRICE€ EX. VAT
UB-40	83 x 48 cm	max. 9,5 m3	35 kg	350 gr.	50 ltr.	1170,00
UB-60	100 x 61 cm	max. 38 m3	100 kg	1000 gr.	120 ltr.	1347,00
UB-100	110 x 76 cm	max. 57 m3	135 kg	1350 gr.	170 ltr.	1810,00
UB-140	120 x 92 cm	max. 95 m3	200 kg	2000 gr.	255 ltr.	2418,00

All models are standard equipped with a 2" multi-port valve, a transparent access cap and a powerful blower.

UltraBead® filters are constructed from high quality fibreglass conforming drink water standards so they are completely save for your fish.

There is a warranty period of 5 years on the pipe- and fitting system.

There is a warranty period of 10 years on the fibreglass vessel and beads.

Nanofiltration Pilot Size Specifications

	Diameter (cm)	Length (cm)	Volume (cm^3)	Volume (L)
Pressure Vessel 1	20	135	42411	42,4
Pressure Vessel 2	20	135	42411	42,4
Large Piping	9	730	46441	46,4
Small Piping	4	240	3016	3,0
Cartridge Filter	20	50	15708	15,7
Total Volume (L)				150
Total Available Volume for Fluid* (L)				108

*assumption: 50% of pressure vessel volume is taken up by membrane

APPENDIX B

MANUFACTURER MATERIAL SPECIFICATIONS

Lewatit® VPOC 1071 Resin Materials Safety Data Sheet (MSDS)-Partial Report

MATERIAL SAFETY DATA SHEET

LANXESS

LANXESS Sybron

LANXESS Corporation
Sybron Chemicals, Inc
200 Birmingham Road
Birmingham, NJ 08011
USA

TRANSPORTATION EMERGENCY
CALL CHEMTREC: (800) 424-9300
INTERNATIONAL: (703) 527-3887

NON-TRANSPORTATION
LANXESS Emergency Phone: (609) 893-1100
LANXESS Information Phone: (609) 893-1100

1. Product and Company Identification

Product Name: Lewatit OC 1071 (5392B)
Material Number: SY003947
Chemical Name: Acrylic acid-divinylbenzene-copolymer with trimethylammonium-propylamido groups in chloride form

2. Hazards Identification

Emergency Overview

Color: White **Form:** Solid Beads **Odor:** Odorless.
Product poses little or no hazard if spilled.

Potential Health Effects

Primary Routes of Entry: Inhalation, Skin Contact, Eye Contact, Ingestion

Medical Conditions Aggravated by Exposure: Respiratory disorders

HUMAN EFFECTS AND SYMPTOMS OF OVEREXPOSURE

Eye
Acute Eye
For Product: Lewatit OC 1071 (5392B)
May cause mechanical irritation.

General Effects of Exposure
Acute Effects of Exposure
For Product: Lewatit OC 1071 (5392B)
Not expected to cause any adverse acute health effects.

7. Handling and Storage

Storage Temperature:

minimum:	0 °C (32 °F)
maximum:	40 °C (104 °F)

Storage Period
12 Months: (Approximate value)

Handling/Storage Precautions
Handle in accordance with good industrial hygiene and safety practices. Wash thoroughly after handling. Keep container closed when not in use. Avoid breathing dust.

Further Info on Storage Conditions
Protect from freezing.

8. Exposure Controls / Personal Protection

Country specific exposure limits have not been established or are not applicable

Industrial Hygiene/Ventilation Measures
Under normal conditions of use, special ventilation is not required.

Respiratory Protection
None required under normal conditions of use.

Eye Protection
safety glasses.

Skin and body protection
No special skin protection requirements during normal handling and use.

Additional Protective Measures
Employees should wash their hands and face before eating, drinking, or using tobacco products. Educate and train employees in the safe use and handling of this product.

9. Physical and chemical properties

Form:	Solid
Appearance:	Beads
Color:	White
Odor:	Odorless
pH:	7 - 9 aqueous suspension
Freezing Point:	approximately 0 °C (32 °F)
Boiling Point/Range:	approximately 100 °C (212 °F)
Flash Point:	Not Established
Lower Explosion Limit:	Not Established
Upper Explosion Limit:	Not Established
Vapor Pressure:	22.7 mbar @ 20 °C (68 °F)
Specific Gravity:	approximately 1.08
Solubility in Water:	Practically insoluble
Autoignition Temperature:	> 250 °C (> 482 °F)
Decomposition Temperature:	Not established

Bulk Density: approximately 720 kg/m3

10. Stability and Reactivity

Hazardous Reactions
Hazardous polymerization does not occur.

Stability
Stable

11. Toxicological Information

Toxicity Data for Lewatit OC 1071 (5392B)
Toxicity Note
Toxicity data is based on a similar product.

Acute dermal toxicity
LD50: > 2,000 mg/kg (Rat)

Skin Irritation
rabbit, Exposure Time: 24 h, Non-irritating

Eye Irritation
rabbit, Non-irritating

Toxicity Data for 1-Propanaminium, N,N,N-trimethyl-3-[(1-oxo-2-propenyl)amino]-, chloride, polymer with diethenylbenzene and 1,1'-[oxybis(2
Toxicity Note
Toxicity data is based on a similar product.

Acute Oral Toxicity
LD50: > 5,000 mg/kg (Rat)

Skin Irritation
rabbit, Exposure Time: 4 h, Non-irritating

Eye Irritation
rabbit, Non-irritating

12. Ecological Information

Ecological Data for Lewatit OC 1071 (5392B)
Additional Ecotoxicological Remarks
No data available for this product.

13. Disposal considerations

FILMTEC NF270-400 Nanofiltration Element Specifications Sheet

Product Information

FILMTEC Membranes

FILMTEC NF270-400 Nanofiltration Element

Features

The FILMTEC™ NF270-400 element is a high area, high productivity element designed to remove a high percentage of TOC and THM precursors while having a medium to high salt passage; medium hardness passage.

The FILMTEC NF270-400 element is an ideal element for surface and ground water applications where good organic removal is desired with partial softening in order to maintain a minimum level of hardness for organoleptic properties and preservation of distribution networks.

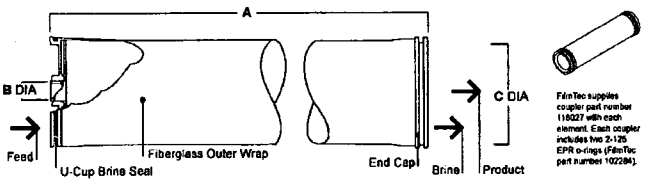
The high active area membrane combined with low net driving pressure of the membrane allows the removal of these compounds at low operating pressure.

Product Specifications

Product	GMID	Nominal Active Surface Area ft^2 (m^2)	Product Water Flow Rate gpd (m^3/d)	Stabilized Salt Passage (%)
NF270-400	148822	400 (37)		
$CaCl_2$			14,700 (55.6)	40-60
$MgSO_4$			12,500 (47.3)	< 3

1. Permeate flow and salt passage based on the following test conditions:
   500 mg/l $CaCl_2$, 70 psi (0.48 MPa), 77°F (25°C) and 15% recovery.
   2,000 mg/l $MgSO_4$, 70 psi (0.48 MPa), 77°F (25°C) and 15% recovery.
2. Flow rates for individual elements may vary +/-15%.
3. The above specifications are benchmark values. Please be sure to operate according to our system design guidelines.

Figure 1



Product	Single-Element Recovery	Dimensions – Inches (mm) A	B	C
NF270-400	15%	40 (1,016)	1.5 (38)	7.9 (201)

1. Refer to FilmTec Design Guidelines for multiple-element applications and recommended element recovery rates for various feed sources.
2. Element to fit nominal 8.00-inch (203 mm) I.D. pressure vessel.

Form No. 609-00346-603

Operating Limits

• Membrane Type	Polyamide Thin-Film Composite
• Maximum Operating Temperature	113°F (45°C)
• Maximum Operating Pressure	600 psig (41 bar)
• Maximum Pressure Drop	15 psig (1.0 bar)
• pH Range, Continuous Operation[a]	3 – 10
• pH Range, Short-Term Cleaning (30 min.)[b]	1 – 12
• Maximum Feed Flow	70 gpm (15.9 m^3/hr)
• Maximum Feed Silt Density Index	SDI 5
• Free Chlorine Tolerance[c]	<0.1 ppm

[a] Maximum temperature for continuous operation above pH 10 is 95°F (35°C).
[b] Refer to Cleaning Guidelines in specification sheet 609-23010.
[c] Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty, FilmTec recommends removing residual free chlorine by pretreatment prior to membrane exposure. Please refer to technical bulletin 609-22010 for more information.

Important Information

Proper start-up of reverse osmosis water treatment systems is essential to prepare the membranes for operating service and to prevent membrane damage due to overfeeding or hydraulic shock. Following the proper start-up sequence also helps ensure that system operating parameters conform to design specifications so that system water quality and productivity goals can be achieved.

Before initiating system start-up procedures, membrane pretreatment, loading of the membrane elements, instrument calibration and other system checks should be completed.

Please refer to the application information literature entitled "Start-Up Sequence" (Form No. 609-00298) for more information.

Operation Guidelines

Avoid any abrupt pressure or cross-flow variations on the spiral elements during start-up, shutdown, cleaning or other sequences to prevent possible membrane damage. During start-up, a gradual change from a standstill to operating state is recommended as follows:

- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.
- Permeate obtained from first hour of operation should be discarded.

General Information

- Keep elements moist at all times after initial wetting.
- If operating limits and guidelines given in this bulletin are not strictly followed, the limited warranty will be null and void.
- To prevent biological growth during prolonged system shutdowns, it is recommended that membrane elements be immersed in a preservative solution.
- The customer is fully responsible for the effects of incompatible chemicals and lubricants on elements.
- Maximum pressure drop across an entire pressure vessel (housing) is 50 psi (3.4 bar).
- Avoid permeate-side backpressure at all times.

Distributed By:
APPLIED MEMBRANES INC.®
2325 Cousteau Ct., Vista, CA 92081 · (760) 727-3711 · FAX (760) 727-4427
http://www.appliedmembranes.com · sales@appliedmembranes.com

DOW®

Salt Specifications from www.kloekzout.nl (translated from Dutch to English using google.com translator)

Vacuum Salt:

Vacuum salt is extracted by the evaporation of brine. Through pipelines, water in underground salt chambers is pumped. This water becomes saturated with salt creating brine. This brine is then pumped up and transported to the evaporation plant. Here, the water is evaporated under vacuum until the salt grain remains. After centrifugation and drying remains a very pure grain of salt.

- Vacuum salt has a purity (% NaCl) of 99.9%
- The average grain size is 0.38 mm, but there are larger groups available.

APPENDIX C

HWL CERTIFICATIONS AND PROCEDURES

HWL Accreditation

RAAD VOOR ACCREDITATIE

PO Box 2768 NL-3500 GT Utrecht

De Stichting Raad voor Accreditatie, opererend als accreditatieverlener voor testlaboratoria, verklaart hierbij dat

Het Waterlaboratorium N.V.
HAARLEM

voldoet aan de accreditatiecriteria voor testlaboratoria zoals vastgelegd in NEN-EN-ISO/IEC 17025:2005. De accreditatie omvat het kwaliteitssysteem van het laboratorium alsmede de specifieke verrichtingen en onderzoeksgebieden zoals omschreven in de gewaarmerkte bijlage die is voorzien van het accreditatienummer.

De accreditatie is van kracht, vooropgezet dat het laboratorium blijft voldoen aan de door de Stichting Raad voor Accreditatie vastgestelde criteria.

Dit certificaat met accreditatienummer:

L404

is verleend op 19 december 2006 en is geldig tot
1 januari 2011

De accreditatie is voor het eerst verleend op
1 januari 2003

De Algemeen Directeur

Ir. J.C. van der Poel

ACCREDITATIE CERTIFICAAT

Bijlage bij NEN-EN-ISO/IEC 17025 accreditatie-certificaat
nummer: **L 404**

van **Het Waterlaboratorium N.V.**
Haarlem

Geldig van: **14-10-2008** tot **01-01-2011** Vervangt bijlage d.d.: **31-01-2008**

Nr.	Materiaal of product	Verrichting / Onderzoeksmethode	Intern referentienummer
		Monsterneming	
a	Drink, oppervlakte- en proceswater	Monsterneming via tapkranen t.b.v. alle in deze lijst opgesomde anorganische- en organische analyses	MVS-TAPKCHEM eigen methode
b		Monsterneming via tapkranen t.b.v. alle in deze lijst opgesomde microbiologische analyses; behalve voor verrichting AVS-LEG (Legionella)	MVS-TAPKBAC conform NEN 6559
c		Monsterneming via tapkranen t.b.v. de Legionellabepaling (verrichting met intern referentienummer AVS-LEG)	MVS-LEG eigen methode
d	Oppervlakte-water	Monsterneming van open water t.b.v. alle in deze lijst opgesomde analyses	MVS-OPENW conform NEN 6600-2
e	Grondwater	Monsterneming via waarnemingsputten t.b.v. alle in deze lijst opgesomde anorganische-, organische- en microbiologische analyses	MVS-WAARNPUT conform NEN 5744 en conform NEN 5745
f	Drinkwater	Monsterneming via brandkranen t.b.v. hydrobiologisch onderzoek (verrichting met intern referentienummer AVS-ZOO-N-SW)	MVS-BRANDK-Hydro eigen methode
g	Drink-, oppervlakte- en proceswater	Monsterneming via tapkranen t.b.v. hydrobiologisch onderzoek (verrichtingen met interne referentienummers AVS-ZOO-N)	MVS-TAPK-Hydro eigen methode
		Veldmetingen	
1	Alle soorten water	Het bepalen van de temperatuur (Pt-100); elektrochemie	MVS-TEMP conform NEN 6414
		Anorganische analyses (nat-chemisch)	
2	Drink-, grond en oppervlakte-water	Het bepalen van het gehalte aan gesuspendeerde stoffen (>1.5 µm); gravimetrie	AVS-SUSP-ST gelijkwaardig aan NEN-EN 872 (1996)

Deze bijlage is goedgekeurd door:

Ir. J.C. van der Poel
Algemeen Directeur

Bijlage bij NEN-EN-ISO/IEC 17025 accreditatie-certificaat
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Nr.	Materiaal of product	Verrichting / Onderzoeksmethode	Intern referentienummer
3	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het elektrisch geleidend vermogen bij 20 °C; conductometrie	AVS-ROBOT conform ISO 7888
4		Het bepalen van het gehalte aan zuurstof; elektrochemie	AVS-ROBOT conform ISO 5814
5		Het bepalen van de zuurgraad; potentiometrie	AVS-ROBOT eigen methode
6		Het bepalen van het gehalte aan carbonaat en waterstofcarbonaat; potentiometrische titrimetrie	AVS-ROBOT eigen methode
7	Drink-, grond en oppervlakte-water	Het bepalen van het gehalte aan organische koolstof; infraroodspectrometrie	AVS-TOC conform NEN-EN 1484
8	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van de UV-extinctie bij 254 nm; spectrofotometrie	AVS-UV eigen methode
9		Het bepalen van de kleurintensiteit bij 455 nm; spectrofotometrie	AVS-KLEUR eigen methode
10	Drink-, opper-vlakte- en proceswater	Het bepalen van het gehalte aan non-ionogene- en kation-actieve detergentia; spectrofotometrie	AVS-DET-NONKAT eigen methode
11		Het bepalen van het gehalte aan anion-actieve detergentia; spectrofotometrie	AVS-DET-AN eigen methode
12	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van de som van de gehalten aan stikstofverbindingen volgens Kjeldahl; spectrofotometrie, doorstroomanalysetechniek	AVS-N-KJ conform NEN 6646 (2006)
13		Het bepalen van het gehalte aan nitraat; spectrofotometrie, doorstroomanalysetechniek	AVS-NO3 eigen methode
14		Het bepalen van het gehalte aan totaal-fosfaat; spectrofotometrie, doorstroomanalysesysteem	AVS-PO4-T eigen methode
15		Het bepalen van het gehalte aan totaal cyanide; spectrofotometrie, doorstroomanalysetechniek	AVS-CN-T conform ISO 14403 (2002)

Bijlage bij NEN-EN-ISO/IEC 17025 accreditatie-certificaat
nummer: **L 404**

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Haarlem

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Nr.	Materiaal of product	Verrichting / Onderzoeksmethode	Intern referentienummer
16	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan nitriet; spectrofotometrie, discrete analyzer	AVS-AQUAKEM eigen methode
17		Het bepalen van het gehalte aan vrij ammonium; spectrofotometrie (discrete analyzer)	AVS-AQUAKEM eigen methode
18		Het bepalen van het gehalte aan orthofosfaat; spectrofotometrie, discrete analyzer	AVS-AQUAKEM eigen methode
19		Het bepalen van het gehalte aan chloride; spectrofotometrie (discrete analyzer)	AVS-AQUAKEM eigen methode
20		Het bepalen van het gehalte aan silicaat; spectrofotometrie (discrete analyzer)	AVS-AQUAKEM eigen methode
21	Drink-, grond- en oppervlakte-water	Het bepalen van het gehalte aan fluoride; ionchromatografie	AVS-F conform NEN-EN-ISO 10304-1
22	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan bromide en chloraat; ionchromatografie (geleidbaarheid en UV)	AVS-BR-CLO3 bromide-conform NEN-EN-ISO 10304-1, chloraat conform NEN-EN-ISO 10304-4
23		Het bepalen van het gehalte aan bromaat; ionchromatografie (geleidbaarheid en UV)	AVS-BROMAAT eigen methode
		Anorganische analyses (metaalanalyses)	
24	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan metalen; ICP-AES barium, ijzer, mangaan en zink	AVS-Mn eigen methode
25	Drink-, grond-, oppervlakte- en proceswater, grondstoffen en destruaten	Het bepalen van het gehalte aan metalen; ICP-AES zwavel als sulfaat, natrium, kalium, calcium en magnesium	AVS-MET-STDV conform NEN 6966
26	Drinkwater	Het bepalen van het gehalte van metalen; ICP-MS beryllium, aluminium, vanadium, chroom, kobalt, nikkel, koper, arseen, seleen, zilver, cadmium, antimoon en lood	AVS-MET-MS conform NEN-EN-ISO 17294-1 en NEN-EN-ISO 17294-2

Bijlage bij NEN-EN-ISO/IEC 17025 accreditatie-certificaat
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Nr.	Materiaal of product	Verrichting / Onderzoeksmethode	Intern referentienummer
27	Grond-, oppervlakte- en proceswater	Het bepalen van het gehalte van metalen; ICP-MS beryllium, vanadium, chroom, kobalt, nikkel, koper, arseen, seleen, zilver, cadmium, antimoon en lood	AVS-MET-MS-OW conform NEN-EN-ISO 17294-1 en NEN-EN-ISO 17294-2
28	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan kwik; fluorescentiespectrometrie	AVS-HG conform NEN-EN-ISO 10304-1 (1995)
		Organische analyses	
29	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan niet vluchtige adsorbeerbare organische halogeenverbindingen (AOX); microcoulometrie	AVS-AOX eigen methode
30		Het bepalen van het gehalte aan de complexvormers NTA, EDTA en DTPA; HPLC-UV	AVS-COMPLVM eigen methode
31		Het bepalen van het gehalte aan polycyclische aromatische koolwaterstoffen (inclusief de 6 van Borneff); HPLC-UV/FLU na vaste fase extractie naftaleen, acenaftyleen, acenafteen, fluoreen, phenanthreen, anthraceen, fluorantheen, pyreen, benzo(a)anthraceen, chryseen, benzo(b)fluorantheen, benzo(k)fluorantheen, benzo(a)pyreen, dibenzo(a,h)anthraceen, benzo(g,h,i)peryleen en indeno(1,2,3-c,d)pyreen en de som PAK, 6 van Borneff	AVS-PAK eigen methode
32		Het bepalen van het gehalte aan fenolische bestrijdingsmiddelen; HPLC-UV-DAD na vaste fase extractie dinoseb, dinoterb, 2,4-dinitrofenol en DNOC	AVS-FEN-BM eigen methode
33		Het bepalen van het gehalte aan fenylureum herbiciden; HPLC-UV-DAD na vaste fase extractie chloortoluron, diuron, 3-(3,4-dichloorfenyl)-ureum, 3-(3,4-dichloorfenyl)-1-methylureum, linuron, methabenzthiazuron, metobromuron, metoxuron, monuron, isoproturon, carbamazepine, atrazin, simazin en trifenylfosfineoxide	AVS-FU-HER eigen methode
34		Het bepalen van het gehalte aan N-methylcarbamaten; HPLC-FLU en nakolomderivatisering 3-hydroxycarbofuran, aldicarb, aldicarb-sulfon, butocarboxim-sulfon, carbaryl, carbofuran, methiocarb, methomyl, oxamyl, propoxur, thiofanoxsulfon, thiofanoxsulfoxide, aldicarb-sulfoxide, butocarboxim, butocarboxinsulfoxide, ethiofencarb en methiocarbsulfon	AVS-NMC eigen methode

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Nr.	Materiaal of product	Verrichting / Onderzoeksmethode	Intern referentienummer
35	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan gehalogeneerde koolwaterstoffen; GC-ECD na extractie broomchloormethaan, trichloormethaan, 1,2-dichloorethaan, 1,1,1-trichloorethaan, tetrachloormethaan, broomdichloormethaan, trichlooretheen, 1,1,2-trichloorethaan, dibroomchloormethaan, tetrachlooretheen, tribroommethaan, 1,1,2,2-tetrachloorethaan, 1,2,3-trichloorpropaan en de som van trihalomethanen	AVS-VGK eigen methode
36		Het bepalen van het gehalte aan organochloorbestrijdingsmiddelen, polychloorbifenylen en chloorbenzenen; GC-ECD na extractie dichlobenil, alfa-HCH, hexachloorbenzeen, beta-HCH, gamma-HCH, heptachloor, aldrin, cis-heptachloorepoxide, trans-heptachloorepoxide, alfa-endosulfan, p,p'-DDE, dieldrin, endrin, p,p'-DDD, p,p'-DDT, 2,4,4'-trichloorbifenyl, 2,5,2',5'-tetrachloorbifenyl, 2,4,5,2',5'-pentachloorbifenyl, 2,4,5,4',4'-pentachloorbifenyl, 2,3,4,2',4',5'-hexachloorbifenyl, 2,4,5,2',4',5'-hexachloorbifenyl, 2,3,4,5,2',4',5'-heptachloorbifenyl, 1,3-dichloorbenzeen, 1,4-dichloorbenzeen, 1,2-dichloorbenzeen, hexachloorethaan, 1,3,5-trichloorbenzeen, 1,2,4-trichloorbenzeen, 1,2,3-trichloorbenzeen, hexachloorbutadieen, 1,2,4,5-tetrachloorbenzeen, 1,2,3,4-tetrachloorbenzeen en pentachloorbenzeen	AVS-CHLBENZ-OCB-PCB eigen methode
37	Drink-, oppervlakte- en proceswater	Het bepalen van het gehalte aan gehalogeneerde organocarbonzuren; GC-ion-trap na extractie en methylering monochloorazijnzuur, monobroomazijnzuur, dichloorazijnzuur, trichloorazijnzuur, broomchloorazijnzuur en dibroomazijnzuur	AVS-GOC eigen methode
38	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan chloorfenolen; GC-MS na extractie 2-monochloorfenol, 3-monochloorfenol, 4-monochloorfenol, 2,6-dichloorfenol, som van 2,4-dichloorfenol en 2,5-dichloorfenol, 3,5-dichloorfenol, 2,3-dichloorfenol, 3,4-dichloorfenol, 2,4,6-trichloorfenol, 2,3,6-trichoorfenol, 2,3,5-trichloorfenol, 2,4,5-trichloorfenol, 2,3,4-trichloorfenol, 3,4,5-trichloorfenol, 2,3,5,6-tetrachloorfenol, 2,3,4,6-tetrachloorfenol, 2,3,4,5-tetrachloorfenol en pentachloorfenol	AVS-CHLFENOL eigen methode

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Nr.	Materiaal of product	Verrichting / Onderzoeksmethode	Intern referentienummer
39	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan stikstof- en fosforhoudende bestrijdingsmiddelen (NPB) en trifosfaten; GC-MS na vaste fase extractie (SPE) atrazin, azinfos-methyl, bromacil, carbamazepine, cyanazin, desethylatrazin, desisopropylatrazin, desmetryn, diazinon, dichloorvos, dimethoaat, edinfenfos, ethoprofos, fenpropimorf, malathion, metamitron, metazachloor, metolachloor, metribuzin, mevinfos, paraoxon-ethyl, parathion-ethyl, parathion-methyl, pirimicarb, prometryn, propazin, pyrazofos, simazin, terbutryn, terbutylazin, terbutylazin-desethyl, tetrachloorvinfos, tolclofos-methyl, triadimefon, triadimenol, tri-isobutylfosfaat, tributylfosfaat en triethylfosfaat	AVS-NPB eigen methode
40	Drink-, oppervlakte- en proceswater	Het bepalen van het gehalte aan vluchtige organische koolwaterstoffen; GC-MS na purge & trap dichloormethaan, trans-1,2-dichlooretheen, MTBE, cis-1,2-dichlooretheen, diisopropylether, trichloormethaan (THM), ETBE, 1,2-dichloorethaan, 1,1,1-trichloorethaan, benzeen, tetrachloormethaan, cyclohexaan, TAME, 1,2-dichloorpropaan, dichloorbroommethaan (THM), trichlooretheen, cis-1,3-dichloorpropeen, trans-1,3-dichloorpropeen, methylbenzeen, 1,3-dichloorpropaan, dibroomchloormethaan (THM), tetrachlooretheen, chloorbenzeen, ethylbenzeen, 1,3 + 1,4-dimethylbenzeen, tribroommethaan (THM), ethenylbenzeen, 1,2-dimethylbenzeen, 1,2,3-trichloorpropaan, iso-propylbenzeen, 2-chloormethylbenzeen, n-propylbenzeen, 1,3,5-trimethylbenzeen, 1,2,4-trimethylbenzeen, iso-butylbenzeen, p-isopropylmethylbenzeen, n-butylbenzeen, 1,2-dibroom-3-chloorpropaan, 1,1,2,2-tetrachloorethaan, 1,1,2-trichloorethaan, broomchloormethaan en de som trihalomethanen (THM)	AVS-VOV eigen methode
41	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan chloorfenoxycarbonzuren; GC-MS na SPE dicamba, mecoprop, MCPA, 2,4-DP, 2,4-D, 2,4,5-T, MCPB, bentazon, metolachloor, chlortal en tetrachlooorthoftaalzuur	AVS-CHLFENC-ZG eigen methode
42		Het bepalen van natuurlijk organisch materiaal (NOM) in water; LC-OCD-OND TOC, DOC en CDOC-fracties inclusief POC (TOC minus DOC) en HOC (DOC minus CDOC): biopolymeren, humusverbindingen, building blocks, zuren en neutralen	AVS-NOM eigen methode

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Nr.	Materiaal of product	Verrichting / Onderzoeksmethode	Intern referentienummer
		Microbiologische analyses	
43	Drink-, grond-, oppervlakte-, proces- en zwemwater	Het bepalen van het koloniegetal bij 36 °C; gietplaatmethode	AVS-KG22-KG36 conform NEN-EN-ISO 6222
44		Het bepalen van het koloniegetal bij 22 °C; gietplaatmethode	AVS-KG22-KG36 conform NEN-EN-ISO 6222
45		Het bepalen van het koloniegetal bij 25°C; strijkplaatmethode	AVS-KG25 conform NEN 6276
46		Het bepalen van het aantal bacteriën van de coligroep en het aantal Escherichia coli; membraanfiltratie	AVS-COLI gelijkwaardig aan NEN-EN-ISO 9308-1
47		Het bepalen van het aantal kolonievormende eenheden van Escherichia coli; membraanfiltratie	AVS-ECOLI-DP conform NEN-EN-ISO 9308-1
48		Het bevestigen van Escherichia coli verdachte kolonies; realtime-PCR	AVS-ECOLI-B-QPCR eigen methode
49		Het bepalen van het aantal Aeromonas-bacteriën; membraanfiltratie	AVS-AERO conform NEN 6263
50		Het bepalen van het aantal sulfietreducerende clostridia; membraanfiltratie	AVS-CLOS conform NEN 6567
51	Drink-, grond-, oppervlakte-, en zwemwater	Het bepalen van het aantal Legionella bacteriën; membraanfiltratie	AVS-LEG conform NEN 6265
52	Drink-, grond-, oppervlakte-, proces- en zwemwater	Het aantonen van enterococcen; membraanfiltratie	AVS-ENT conform NEN-EN-ISO-7899-2
53	Drink-, grond-, oppervlakte- en zwembadwater	Het aantonen van thermofiele campylobacters; MPN-methode	AVS-CAMP conform NEN 6269
54	Drink-, grond-, oppervlakte- en proceswater	Het determineren van bacteriën van de coligroep en thermotolerante bacteriën van de coli-groep; gebruik van API20E-systeem	AVS-API eigen methode

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Nr.	Materiaal of product	Verrichting / Onderzoeksmethode	Intern referentienummer
55	Drink-, grond-, oppervlakte- en proceswater	Het bepalen van het gehalte aan assimileerbaar organisch koolstof (AOC); groeicurvebepaling	AVS-AOC conform NEN 6271
56	Water	Het bepalen van het gehalte aan adenosinetrifosfaat (ATP); spectrofotometrie	AVS-ATP-BIOM eigen methode
		Hydrobiologische analyses	
57	Drink-, oppervlakte- en proceswater	Het benoemen en tellen van zoöplankton op hoofdgroepniveau; microscopie	AVS-ZOO-N eigen methode
58	Drinkwater	Het benoemen en tellen van dierlijke organismen >30 µm; microscopie	AVS-ZOO-N-SW eigen methode
59	Grond- en oppervlakte-water	Het benoemen en tellen van fytoplankton op hoofdgroepniveau; omkeermicroscopie	AVS-FYT-N eigen methode
60	Drink-, oppervlakte- en proceswater	Het bepalen van het gehalte aan Chlorofyl-a; spectrofotometrie	AVS-CHLOROFYL gelijkwaardig aan NEN 6520
		Radioactiviteitsmetingen	
61	Alle soorten water	Het bepalen van de totale en rest-bèta radioactiviteits-concentratie; anticoïncidentie-gasdoorstroomteller	AVS-RAD-BETA eigen methode
62		Het bepalen van het gehalte aan getritieerd water; vloeistof-scintillatietelling	AVS-TRITIUM eigen methode

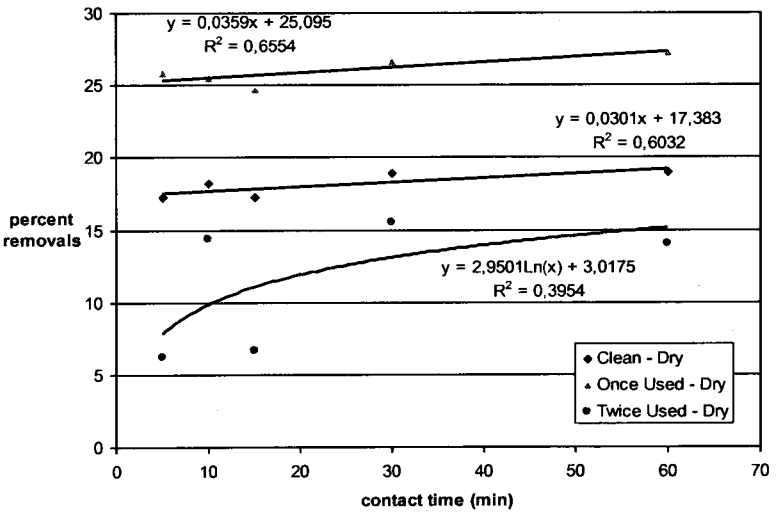
APPENDIX D

RESIN REGENERATION

Times For SIX Resin Regen. Process

Process	Time
Adding Salt	1 min
Stirring	4 min
Settling	2 min
Draining	4 min
Total	11 min

Example of NO_3 desorption being too rapid and sporadic to model



Raw Data from dry resin trials with the clean salt solution

Dry Resin with Clean Salt - Rep 1						
Time	5	10	15	30	60	24hr Stnd
UVT 1	70,9	75,1	76,5	79,6	83,4	77,8
UVT 2	70,6	75,9	77,6	79,7	83,4	77,5
UVT 3	71	76	76,4	79,9	83,5	77,7
UVT Avg	70,8	75,7	76,8	79,7	83,4	77,7
NO3 1	1,91	4,2	4,33	4,1	4,07	6,72
NO3 2	1,92	4,18	4,3	4,07	4,08	6,73
NO3 3	1,95	4,18	4,32	4,08	4,09	6,75
NO3 Avg	1,9	4,2	4,3	4,1	4,1	6,7
NO3 x50	96,3	209	216	204	204	337

Dry Resin with Clean Salt - Rep 2					
Time	5	10	15	30	60
UVT 1	84,2	81	78,1	74,2	69,7
UVT 2	84,3	81,1	78,2	74,3	69,7
UVT 3	84,6	81	78,2	73,9	70
UVT Avg	84,4	81,0	78,2	74,1	69,8
DOC mg/L	319	368	410	470	533
DOC % Removed	31,9	36,8	41,0	47,0	53,3

Raw Data from dry resin trials with the once used salt solution

Dry Resin with Once Used Salt - Rep 1					
Time	5	10	15	30	60
UVT 1	76,1	72,8	70,4	65,9	63,4
UVT 2	75,7	73,4	70,5	65,9	63
UVT 3	76	73,7	70,4	66	63,1
UVT Avg	75,9	73,3	70,4	65,9	63,2
NO3 1	7,27	7,26	7,15	7,42	7,49
NO3 2	7,32	7,26	7,15	7,42	7,51
NO3 3	7,35	7,28	7,17	7,42	7,54
NO3 Avg	7,31	7,27	7,16	7,42	7,51
NO3 x50	365,7	363	358	371	376
Dry Resin with Once Used Salt - Rep 2					
Time	5	10	15	30	60
UVT 1	77,1	74,5	73,2	68,4	64,7
UVT 2	77,3	74,8	73	68,6	64,7
UVT 3	77,1	74,6	73,2	68,5	64,6
UVT Avg	77,2	74,6	73,1	68,5	64,7
DOC mg/L	425	462	484	553	609
Corrected DOC	222	259	281	350	406
DOC % Removed	31,7	37,1	40,2	49,9	58,0

Raw Data from dry resin trials with the twice used salt solution

Dry Resin with Twice Used Salt - Rep 1					
Time	5	10	15	30	60
UVT 1	73,5	71,1	69,8	66,6	63,1
UVT 2	74	71	69,8	66,5	63,1
UVT 3	74,2	71,1	69,7	66,6	63
UVT Avg	73,9	71,1	69,8	66,6	63,1
NO3 1	7,07	8,22	7,13	8,38	8,17
NO3 2	7,1	8,23	7,14	8,38	8,18
NO3 3	7,1	8,23	7,16	8,39	8,18
NO3 Avg	7,1	8,2	7,1	8,4	8,2
NO3 x50	355	411	357	419	409
Dry Resin with Twice Used Salt - Rep 2					
Time	5	10	15	30	60
UVT 1	72,9	69,6	68,8	66,4	64,1
UVT 2	72,9	70,4	68,5	66,2	64,2
UVT 3	72,9	70,5	68,6	66,3	64,2
UVT Avg	72,9	70,2	68,6	66,3	64,2
UVT Avg	72,9	70,2	68,6	66,3	65,2
DOC (mg/L)	488	528	551	585	602
DOC adjusted	176	216	239	273	290

Analyzed Data from Dry Resin Trials

Clean Salt - Dry Resin R1					
Time (min)	5	10	15	30	60
DOC Percent	31,6	38,7	40,5	44,7	50,2
NO3 Percent	34,3	18,2	17,3	18,9	19,0
Clean Salt – Dry Resin R2					
Time (min)	5	10	15	30	60
UVT Avg	84,4	81,0	78,2	74,1	69,8
DOC mg/L	319,3	368,3	410,5	469,7	533,4
DOC Percent	31,9	36,8	41,0	47,0	53,3
Once Used Salt - Dry Resin R1					
Time (min)	5	10	15	30	60
DOC Percent	24,0	27,9	32,1	38,7	42,8
NO3 Percent	25,8	25,5	24,7	26,6	27,2
Once Used Salt – Dry Resin R2					
Time (min)	5	10	15	30	60
UVT Avg	77,2	74,6	73,1	68,5	64,7
DOC mg/L	222	259	281	350	406
DOC Percent	22,2	25,9	28,1	35,0	40,6
Twice Used Salt - Dry Resin R1					
Time (min)	5	10	15	30	60
DOC Percent	16,1	20,2	22,1	26,9	32,0
NO3 Percent	6,2	14,4	6,6	15,5	14,0

Twice Used Salt – Dry Resin R2					
Time (min)	5	10	15	30	60
UVT Avg	72,9	70,2	68,6	66,3	65,2
DOC mg/L	175	216	238	272	289
DOC Percent	17,5	21,6	23,8	27,2	28,9

The raw data set from jar tests run on the pilot to test the non-optimized conditions

Previous Regeneration Method						
	21-4-2009			28-4-2009		
	12:00	14:00	16:00	9:00	10:00	11:00
UVT 1	80,8	77,2	79	76,5	76,7	75,6
UVT 2	81	77,3	79,3	76,6	76,8	76,1
UVT 3	81	77,3	79,3	76,7	76,7	75,9
NO3 1	1,99	2,35	2,27	2,76	2,43	2,56
NO3 2	2,01	2,38	2,31	2,8	2,45	2,58
NO3 3	2,02	2,39	2,32	2,8	2,46	2,59
UVT Avg	80,9	77,3	79,2	76,6	76,7	75,9
DOC mg/L	370	424	395	433	432	444
NO3 mg/L	100	119	115	139	122	129

DOC Avg All	StDev All
416	28
121	13

Percent Efficiency	
DOC	58,4
NO3	82,8

The raw data set from jar tests on the pilot with the new optimized method in place

Optimized Regeneration Method						
	Trial 1			Trial 2		
UVT 1	79,3	78,9	78,6	78,4	80,3	76,8
UVT 2	79,3	78,8	78,4	78,2	80,2	76,9
UVT 3	79,3	78,8	78,5	78,3	80,3	77
NO3 1	2,2	2,1	2,35	2,13	2,02	2,21
NO3 2	2,23	2,13	2,37	2,14	2,01	2,2
NO3 3	2,23	2,14	2,38	2,13	2,01	2,21
UVT Avg	79,3	78,8	78,5	78,3	80,3	76,9
DOC mg/L	394	401	406	408	380	429
NO3 mg/L	111	106	118	107	101	110

	Avg All	StDev All	Percent Efficiency	
DOC mg/L	403	16	DOC	59,7
NO3 mg/L	109	6	NO3	84,4

Sample calculation set-up to show time reductions possibilities for new optimized method of regeneration.

Dry Resin Trials		
DOC Efficiencies for the Current Process		
Step	Time (min)	Approx Removal %
Regen 1 (SV-3)	4	15,7
Regen 2 (SV-2)	4	20,6
Regen 3 (SV-1)	4	30,2
Total	12 minutes	**53,29**
DOC Proposal for Future Process		
Step	Time	Approx Removal %
Regen 1 (SV-3)	0	
Regen 2 (SV-2)	7,3	25,3
Regen 3 (SV-1)	10	37,46
Total	17.3 minutes	**53,26**

Raw Absolute Resin Adsorption Numbers

Dry Resin Rep 1						
Rinse	1	2	3	4	5	6
UVT Avg	76,9	89,0	87,9	87,0	77,9	83,2
DOC	4,29	2,51	2,67	2,80	4,15	3,36
Dilution	100	100	50	25	10	10
DOC mg/L	429,07	251,2	133,685	70,0275	41,486	33,646
NO3 Avg	5,74	3,94	4,52	5,01	19,0	13,0
Dilution	50	50	25	10	1	1
NO3 mg/L	287	197	113	50,1	19,0	13,0

Dry Resin Rep 2						
Rinse	1	2	3	4	5	6
UVT Avg	77,6	89,3	88,6	84,8	74,6	80,9
DOC	4,19	2,47	2,57	3,13	4,63	3,70
Dilution	100	100	50	25	10	10
DOC mg/L	419	247	129	78,4	46,3	37,0
NO3 Avg	5,77	4,19	4,85	5,42	20,77	14,07
Dilution	50	50	25	10	1	1
NO3 mg/L	289	209	121	54,2	20,8	14,1

Absolute Cumulative Resin Adsorption Numbers

Rep 1 Cumulative for DOC and NO3						
Rinse	1	2	3	4	5	6
DOC	429	680	814	884	925	959
NO3	287	484	597	647	666	679
Rep 1 Cumulative for DOC and NO3						
Rinse	1	2	3	4	5	6
DOC	419	666	794	872	919	956
NO3	289	498	619	673	694	708

Raw sodium and chloride data used to generate salt concentrations

	Salt Vessel 1			Salt Vessel 2			Salt Vessel 3		
Datum	Cl	Na	NaCl	Cl	Na	NaCl	Cl	Na	NaCl
	mg/l	mg/l	mg/L	mg/l	mg/l	mg/L	mg/l	mg/l	mg/L
30-7-2008	63500	42300	105800	52500	34200	86700	38000	27500	65500
6-8-2008	43500	38000	81500	35500	35200	70700	35500	28200	63700
13-8-2008	71500	27300	98800	52500	32200	84700	36000	26100	62100
19-11-2008	63000	39500	102500	55000	35300	90300	41500	29500	71000
26-11-2008	63000	47200	110200	50500	40300	90800	35500	34200	69700
3-12-2008	67000	41200	108200	53500	35400	88900	39000	29000	68000
10-12-2008	73500	41400	114900	47500	36000	83500	33500	28500	62000
17-12-2008	64000	38300	102300	54500	32800	87300	42500	29100	71600
8-1-2009	66000	39400	105400	49500	34500	84000	33500	28200	61700
22-1-2009	62000	38400	100400	47000	33800	80800	32000	28000	60000
28-1-2009	51500	42400	93900	44000	35900	79900	36000	31500	67500
5-2-2009	62000	39500	101500	42500	33700	76200	40500	32100	72600
11-2-2009	62000	38900	100900	48500	33500	82000	40000	31400	71400
18-2-2009	65500	39600	105100	45500	37100	82600	35000	30000	65000
25-2-2009	65000	40600	105600	47000	34200	81200	35000	28900	63900
4-3-2009	60000	39400	99400	48000	34300	82300	34500	29100	63600
11-3-2009	62000	39400	101400	49500	33500	83000	35500	28900	64400
18-3-2009	63000	39400	102400	49500	33800	83300	36500	29000	65500
25-3-2009	65000	43000	108000	68500	41000	109500	47000	36400	83400
1-4-2009	63000	40900	103900	55500	38100	93600	44500	29400	73900
8-04-09	65466	40901	106367	54847	35088	89935	55692	36681	92373
15-04-09	51565	40469	92034	58807	40177	98984	47565	32711	80276
22-04-09	64543	41996	106539	59206	37570	96776	42667	33357	76024
29-04-09	63095	40027	103122	59252	39133	98385	49990	35287	85277
6-05-09	65519	40900	106419	61373	39093	100466	53242	35068	88310
20-05-09	46406	41319	87725	54789	37768	92557	47330	33045	80375
27-05-09	64680	40752	105432	57620	37921	95541	46900	33404	80304
3-06-09	63288	40242	103530	53522	35189	88711	44163	31109	75272
10-06-09	63140	40359	103499	50820	37339	88159	36040	29132	65172
17-06-09	65296	39569	104865						
Avg mg/L			102387			87959			71375
Avg g/L			102,4			88,0			71,4
St Dev g/L			6,6			8,1			8,8

APPENDIX E

HYDRAULICS AND TRACER STUDIES

Calculations for Tracer Study run at ***23.4m^3/hr*** *and* ***32 rpm***

Time Correction (min) = 0,38 the time it takes the pipe water to reach the reactor

Mean Residence Time = **40 min**

$t_i = t - 0{,}38$ $dt = t_i - t_{i-1}$ tank 2 effluent $Ci = abs(EC_i - EC_{i-1})$ ECo = 659,1

Time = t	t_i = time corr.	dt	midpt EC (ms/m)	C_i = dEC abs	$F = C_i/EC_o$	$\Theta = t/tm$	F(Θ) CSTR	F(Θ) CSTR	F(Θ) CSTR
min	min	min	ms/m	--	--	--	4	5	6
0,000	0,000	0,000	77,9	0,000	0,00	0,00	0,0000	0,0000	0,0000
1,000	0,620	0,620	78,7	0,800	0,00	0,0155	0,0000	0,0000	0,0000
2,000	1,620	1,000	77,6	0,300	0,00	0,0405	0,0000	0,0000	0,0000
3,000	2,620	1,000	78,0	0,100	0,00	0,0655	0,0002	0,0000	0,0000
4,000	3,620	1,000	78,1	0,200	0,00	0,0905	0,0005	0,0001	0,0000
5,000	4,620	1,000	78,1	0,200	0,00	0,1155	0,0013	0,0003	0,0001
6,000	5,620	1,000	78,0	0,100	0,00	0,1405	0,0027	0,0008	0,0002
7,000	6,620	1,000	78,2	0,300	0,00	0,1655	0,0047	0,0016	0,0006
8,000	7,620	1,000	78,0	0,100	0,00	0,1905	0,0077	0,0030	0,0012
9,000	8,620	1,000	78,0	0,100	0,00	0,2155	0,0117	0,0050	0,0022
10,000	9,620	1,000	78,0	0,100	0,00	0,2405	0,0167	0,0078	0,0037
11,000	10,620	1,000	79,0	1,100	0,00	0,2655	0,0230	0,0116	0,0059
12,000	11,620	1,000	80,2	2,300	0,00	0,2905	0,0306	0,0164	0,0090
13,000	12,620	1,000	80,8	2,900	0,00	0,3155	0,0394	0,0225	0,0130
14,000	13,620	1,000	82	4,100	0,01	0,3405	0,0495	0,0298	0,0182

*Calculations for Tracer Study run at **23.4m³/hr** and **32 rpm*** CONTINUED									
Time = t	t_i = time corr.	dt	midpt EC (ms/m)	C_i = dEC abs	F = C_i/EC_o	Θ = t/tm	F(Θ) CSTR	F(Θ) CSTR	F(Θ) CSTR
min	min	min	ms/m	--	--	--	4	5	6
17,000	16,620	1,000	92	14,100	0,02	0,4155	0,0876	0,0599	0,0416
18,000	17,620	1,000	96,8	18,900	0,03	0,4405	0,1027	0,0728	0,0523
19,000	18,620	1,000	102	24,100	0,04	0,4655	0,1189	0,0870	0,0645
20,000	19,620	1,000	109	31,100	0,05	0,4905	0,1361	0,1026	0,0783
21,000	20,620	1,000	119	41,100	0,06	0,5155	0,1542	0,1194	0,0936
22,000	21,620	1,000	127	49,100	0,07	0,5405	0,1732	0,1375	0,1104
23,000	22,620	1,000	138	60,100	0,09	0,5655	0,1930	0,1566	0,1286
24,000	23,620	1,000	149	71,100	0,11	0,5905	0,2134	0,1768	0,1481
25,000	24,620	1,000	163	85,100	0,13	0,6155	0,2343	0,1979	0,1689
26,000	25,620	1,000	175	97,100	0,15	0,6405	0,2558	0,2198	0,1908
27,000	26,620	1,000	192	114,100	0,17	0,6655	0,2775	0,2424	0,2138
28,000	27,620	1,000	207	129,100	0,20	0,6905	0,2996	0,2656	0,2376
29,000	28,620	1,000	221	143,100	0,22	0,7155	0,3219	0,2893	0,2622
30,000	29,620	1,000	241	163,100	0,25	0,7405	0,3443	0,3133	0,2874
31,000	30,620	1,000	256	178,100	0,27	0,7655	0,3667	0,3375	0,3130
32,000	31,620	1,000	271	193,100	0,29	0,7905	0,3890	0,3619	0,3390
33,000	32,620	1,000	290	212,100	0,32	0,8155	0,4113	0,3863	0,3653
34,000	33,620	1,000	303	225,100	0,34	0,8405	0,4333	0,4107	0,3916
35,000	34,620	1,000	322	244,100	0,37	0,8655	0,4551	0,4349	0,4179
36,000	35,620	1,000	343	265,100	0,40	0,8905	0,4767	0,4589	0,4440
37,000	36,620	1,000	358	280,100	0,42	0,9155	0,4979	0,4825	0,4699
38,000	37,620	1,000	375	297,100	0,45	0,9405	0,5187	0,5059	0,4954
39,000	38,620	1,000	391	313,100	0,48	0,9655	0,5391	0,5287	0,5205
40,000	39,620	1,000	406	328,100	0,498	0,9905	0,5591	0,5511	0,5451
41,000	40,620	1,000	421	343,100	0,52	1,0155	0,5785	0,5730	0,5691
42,000	41,620	1,000	438	360,100	0,55	1,0405	0,5975	0,5943	0,5925

Calculations for Tracer Study run at ***52.4m^3/hr*** *and* ***32 rpm***

Time Correction (min) = 0,19 the time it takes the pipe water to reach the reactor

Experimental HRT = **19 min**

Theoretic HRT = **20,5 min**

	$t_i = t - 0,38$	$dt = t_i - t_{i-1}$	tank 2 effluent	$Ci = abs(EC_i - EC_{i-1})$	ECo = 308,5				
Time = t	t_i = time corr.	dt	Effluent EC (ms/m)	C_i = dEC abs	$F = C_i/EC_o$	Θ = t/tm	F(Θ) CSTR	F(Θ) CSTR	F(Θ) CSTR
min	min	min	ms/m	--	--	--	6	8	10
0,000	0,000	0,000	82,5	0,000	0,00	0,00	0,000	0,000	0,000
1,000	0,810	0,810	84,0	1,500	0,00	0,04	0,000	0,000	0,000
2,000	1,810	1,000	85,0	2,500	0,01	0,10	0,000	0,000	0,000
3,000	2,810	1,000	84,2	1,700	0,01	0,15	0,000	0,000	0,000
4,000	3,810	1,000	84,0	1,500	0,00	0,20	0,002	0,000	0,000
5,000	4,810	1,000	83,8	1,300	0,00	0,25	0,005	0,001	0,000
6,000	5,810	1,000	83,0	0,500	0,00	0,31	0,011	0,004	0,001
7,000	6,810	1,000	84,1	1,600	0,01	0,36	0,023	0,009	0,004
8,000	7,810	1,000	85,0	2,500	0,01	0,41	0,040	0,019	0,010
9,000	8,810	1,000	87,5	5,000	0,02	0,46	0,064	0,036	0,020
10,000	9,810	1,000	92,0	9,500	0,03	0,52	0,094	0,059	0,038
11,000	10,810	1,000	98,5	16,000	0,05	0,57	0,131	0,091	0,064
12,000	11,810	1,000	109,5	27,000	0,09	0,62	0,174	0,131	0,100
13,000	12,810	1,000	121	38,500	0,12	0,67	0,222	0,178	0,144
14,000	13,810	1,000	138	55,500	0,18	0,73	0,274	0,231	0,198
15,000	14,810	1,000	155	72,500	0,24	0,78	0,328	0,289	0,258
16,000	15,810	1,000	173	90,500	0,29	0,83	0,383	0,350	0,324
17,000	16,810	1,000	193	110,500	0,36	0,88	0,438	0,413	0,392
18,000	17,810	1,000	211	128,500	0,42	0,94	0,492	0,475	0,462
19,000	18,810	1,000	238	155,500	0,50	0,99	0,545	0,536	0,529
20,000	19,810	1,000	253	170,500	0,55	1,04	0,594	0,594	0,594
21,000	20,810	1,000	270	187,500	0,61	1,10	0,641	0,648	0,654

*Calculations for Tracer Study run at **51.4m^3/hr** and **45 rpm***

Time Correction (min) = 0,19 the time it takes the pipe water to reach the reactor Experimental HRT = **19,9 min**

$t_i = t - 0,38$ $dt = t_i - t_{i-1}$ tank 2 effluent $Ci = abs(EC_i - EC_{i-1})$ ECo = 298,5 Theoretic HRT = **20,9 min**

Time = t	t_i = time corr.	dt	Effluent EC (ms/m)	C_i = dEC abs	$F = C_i/EC_o$	$\Theta = t/tm$	F(Θ) CSTR	F(Θ) CSTR	F(Θ) CSTR	F(Θ) CSTR
min	min	min	ms/m	--	--	--	6	8	9	10
0,000	0,000	0,000	82,5	0,000	0,00	0,00	0,000	0,000	0,000	0,000
1,000	0,810	0,810	82,5	0,000	0,00	0,04	0,000	0,000	0,000	0,000
2,000	1,810	1,000	82,5	0,000	0,00	0,09	0,000	0,000	0,000	0,000
3,000	2,810	1,000	82,5	0,000	0,00	0,14	0,000	0,000	0,000	0,000
4,000	3,810	1,000	82,5	0,000	0,00	0,19	0,001	0,000	0,000	0,000
5,000	4,810	1,000	82,0	0,500	0,00	0,24	0,004	0,001	0,000	0,000
6,000	5,810	1,000	82,0	0,500	0,00	0,29	0,009	0,003	0,002	0,001
7,000	6,810	1,000	82,0	0,500	0,00	0,34	0,019	0,007	0,004	0,003
8,000	7,810	1,000	82,0	0,500	0,00	0,39	0,033	0,015	0,010	0,007
9,000	8,810	1,000	80,0	2,500	0,01	0,44	0,053	0,028	0,021	0,015
10,000	9,810	1,000	88,5	6,000	0,02	0,49	0,080	0,048	0,037	0,029
11,000	10,810	1,000	94,5	12,000	0,04	0,54	0,112	0,074	0,061	0,050
12,000	11,810	1,000	103,5	21,000	0,07	0,59	0,151	0,108	0,093	0,080
13,000	12,810	1,000	117	34,500	0,12	0,64	0,194	0,149	0,132	0,117
14,000	13,810	1,000	132	49,500	0,17	0,69	0,241	0,197	0,179	0,163
15,000	14,810	1,000	146	63,500	0,21	0,74	0,291	0,250	0,232	0,217
16,000	15,810	1,000	164	81,500	0,27	0,79	0,343	0,306	0,291	0,277
17,000	16,810	1,000	183	100,500	0,34	0,84	0,396	0,365	0,352	0,340
18,000	17,810	1,000	202	119,500	0,40	0,89	0,449	0,425	0,415	0,406
19,000	18,810	1,000	217	134,500	0,45	0,95	0,500	0,484	0,478	0,472
20,000	19,810	1,000	239	156,500	0,52	1,00	0,550	0,542	0,539	0,536
21,000	20,810	1,000	256	173,500	0,58	1,05	0,597	0,597	0,597	0,598
22,000	21,810	1,000	269	186,500	0,62	1,10	0,642	0,648	0,652	0,655

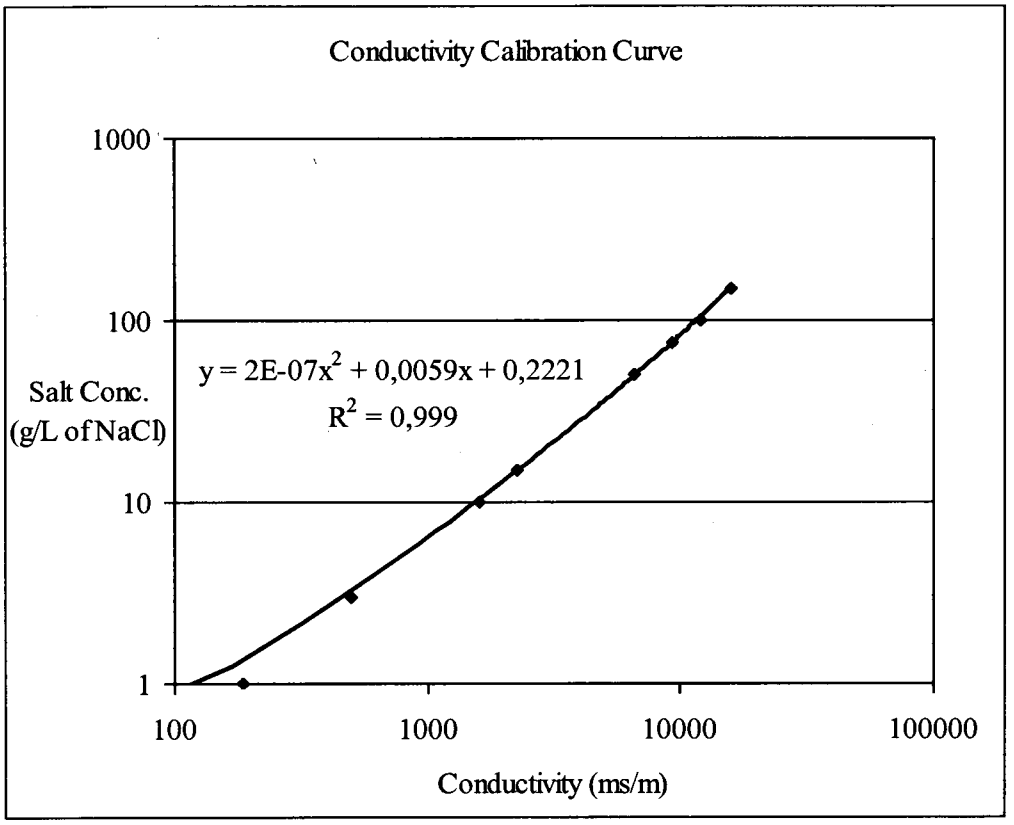
Calculations for Tracer Study run at **52.4m3/hr** and **20 rpm**

Time Correction (min) = 0,19 the time it takes the pipe water to reach the reactor Experimental HRT = **19,5 min**

$t_i = t - 0,38$ $dt = t_i - t_{i-1}$ tank 2 effluent $Ci = abs(EC_i - EC_{i-1})$ ECo = 312,7 Theoretic HRT = **20,5 min**

Time = t	t_i = time corr.	dt	Effluent EC (ms/m)	C_i = dEC abs	$F = C_i/EC_o$	$\Theta = t/tm$	F(Θ) CSTR	F(Θ) CSTR	F(Θ) CSTR	F(Θ) CSTR
min	min	min	ms/m	--	--	--	9	10	11	12
0,000	0,000	0,000	69,3	0,000	0,00	0,00	0,000	0,000	0,000	0,000
1,000	0,810	0,810	69,0	0,300	0,00	0,04	0,000	0,000	0,000	0,000
2,000	1,810	1,000	68,9	0,400	0,00	0,09	0,000	0,000	0,000	0,000
3,000	2,810	1,000	68,9	0,400	0,00	0,14	0,000	0,000	0,000	0,000
4,000	3,810	1,000	68,9	0,400	0,00	0,20	0,000	0,000	0,000	0,000
5,000	4,810	1,000	68,9	0,400	0,00	0,25	0,001	0,000	0,000	0,000
6,000	5,810	1,000	68,8	0,500	0,00	0,30	0,002	0,001	0,001	0,000
7,000	6,810	1,000	68,9	0,400	0,00	0,35	0,005	0,003	0,002	0,001
8,000	7,810	1,000	69,3	0,000	0,00	0,40	0,012	0,008	0,006	0,004
9,000	8,810	1,000	70,3	1,000	0,00	0,45	0,023	0,018	0,013	0,010
10,000	9,810	1,000	72,8	3,500	0,01	0,50	0,042	0,033	0,026	0,021
11,000	10,810	1,000	77,5	8,200	0,03	0,55	0,067	0,056	0,047	0,039
12,000	11,810	1,000	85	15,700	0,05	0,61	0,102	0,088	0,076	0,066
13,000	12,810	1,000	95,6	26,300	0,08	0,66	0,144	0,129	0,115	0,104
14,000	13,810	1,000	110	40,700	0,13	0,71	0,194	0,178	0,164	0,151
15,000	14,810	1,000	128	58,700	0,19	0,76	0,250	0,235	0,221	0,208
16,000	15,810	1,000	149	79,700	0,25	0,81	0,310	0,297	0,284	0,273
17,000	16,810	1,000	169	99,700	0,32	0,86	0,374	0,363	0,353	0,343
18,000	17,810	1,000	192	122,700	0,39	0,91	0,438	0,430	0,423	0,416
19,000	18,810	1,000	214	144,700	0,46	0,96	0,502	0,497	0,493	0,489
20,000	19,810	1,000	239	169,700	0,54	1,02	0,563	0,562	0,561	0,560
21,000	20,810	1,000	260	190,700	0,61	1,07	0,621	0,623	0,625	0,627

Figure, Equation and Raw Data used to Equate Conductivity to Salt Concentration



Conc (g/L)	Cond. (mS/m)
0,1	20,50
1	185,7
3	495
10	1591
15	2249
50	6570
75	9240
100	12083
150	15740

Pilot Hydraulic Efficiency Comparison Raw Data

	UVT Reading at Sample Location (m) for **14 mL/L** resin and **20 rpm**									
	0	0,65	2,15	3,65	5,15	6,65	8,15	9,65	11,15	11,75
time in train (min)	0,0	1,1	3,7	6,3	8,9	11,5	14,1	16,8	19,4	20,4
61min	74,5	76	77,9	74,9	79,5	85	87,2	87,4	91,4	**90**
80min	75,3	76	78	78,8	80	85,7	89,3	85,8	91	**91,9**
difference	0,8	0	0,1	3,9	0,5	0,7	2,1	1,6	0,4	1,9
	Cumulative Change in Percent over Distance									
61min	0	1,5	3,4	0,4	5	10,5	12,7	12,9	16,9	**15,5**
80min	0	0,7	2,7	3,5	4,7	10,4	14	10,5	15,7	**16,6**
	Step Change in Percent over Distance									
61min		1,5	1,9	-3	4,6	5,5	2,2	0,2	4	-1,4
80min		0,7	2	0,8	1,2	5,7	3,6	-3,5	5,2	0,9
	Readings Converted to mg/L of DOC (y=-0,147x + 15,595 R^2=0,987)									
61min	4,64	4,42	4,14	4,58	3,91	3,10	2,78	2,75	2,16	2,37
80min	4,53	4,42	4,13	4,01	3,84	3,00	2,47	2,98	2,22	2,09

	UVT Reading at Sample Location (m) for **16mL/L resin** and **45 rpm**									
Distance (m)	0	0,65	2,15	3,65	5,15	6,65	8,15	9,65	11,15	11,75
Time (min)	0,0	1,1	3,7	6,3	8,9	11,5	14,1	16,8	19,4	20,4
64min	76,3	78,8	80,2	81,3	82,4	88	90,3	92,8	93,5	88,7
84min	77,3	79,2	80,2	81,8	82,6	87,6	90	91,4	93	93,6
Difference	1	0,4	0	0,5	0,2	0,4	0,3	1,4	0,5	4,9
	Cumulative Change in Percent over Distance									
64min	0	2,5	3,9	5	6,1	11,7	14	16,5	17,2	12,4
84min	0	1,9	2,9	4,5	5,3	10,3	12,7	14,1	15,7	16,3
	Readings Converted to mg/L of DOC (y=-0,147x + 15,595 R^2=0,987)									
64min	4,38	4,01	3,81	3,64	3,48	2,66	2,32	1,95	1,85	2,56
84min	4,23	3,95	3,81	3,57	3,45	2,72	2,37	2,16	1,92	1,84

APPENDIX F

REGENERATION FLUID REUSE

Raw data used to calculate the K_{sp} values for determining precipitation potentials

	HCO3 (mg/L)	CO3 (mg/L)	SO4 (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Mn (mg/L)	Ba (mg/L)	PO4 (mg/L)	pH
Feed	6523,34	0	13104	16,427	10,533	0,94539	0,11725	0,0331616	9,0	7,4
Permeate	6420,86	0	1615	10,465	5,1632	0,05	0,031	0,005		
Concentrate	6478,2	0	15548	30,375	14,296	1,6619	0,18076	0,0324624		
	HCO_3 (g/L)	CO_3 (g/L)	SO_4 (g/L)	Ca (g/L)	Mg (g/L)	Fe (g/L)	Mn (g/L)	Ba (g/L)	PO4 (g/L)	pOH
Feed	6,52334	0	13,104	0,016427	0,010533	0,00094539	0,00011725	3,3162E-05	0,009	6,6
Permeate	6,42086	0	1,6149	0,010465	0,0051632	0,00005	0,000031	0,000005		
Concentrate	6,4782	0	15,548	0,030375	0,014296	0,0016619	0,00018076	3,2462E-05		
Molecular Weights	61,02	60,01	96,06	40,08	24,31	55,85	54,94	137,33	30,973	
	HCO_3 (mol/L)	CO_3 (mol/L)	SO_4 (mol/L)	Ca (mol/L)	Mg (mol/L)	Fe (mol/L)	Mn (mol/L)	Ba (mol/L)	PO4 (moles/L)	$[OH^-]$ (mol/L)
Feed	1,07E-01	0	1,36E-01	4,10E-04	4,33E-04	1,69E-05	2,13E-06	2,41E-07	0,00029	2,512E-07
Permeate	1,05E-01	0	1,68E-02	2,61E-04	2,12E-04	8,95E-07	5,64E-07	3,64E-08		
Concentrate	1,06E-01	0	1,62E-01	7,58E-04	5,88E-04	2,98E-05	3,29E-06	2,36E-07		
	HCO_3 (mol/L)	CO_3 (mol/L)	SO_4 (mol/L)	Ca (mol/L)	Mg (mol/L)	Fe (mol/L)	Mn (mol/L)	Ba (mol/L)	PO4 (mol/l)	[OH-] (mol/L)
Feed x5	5,35E-01	0	6,82E-01	2,05E-03	2,17E-03	8,46E-05	1,07E-05	1,21E-06	0,00145	1,256E-06

NF Installation data gathered for flush determinations WITHOUT second flush

1-7-2009 (Day 1)		Pressures (Bar)				Flows			Flush		
Time (min)	Temp (°C)	Feed	Recirc	Perm	ΔP =Feed-Perm	Recirc (m^3/hr)	Perm (L/hr)	Conc (L/hr)	Freq. (min)	Dur. (sec)	ΔP Gain
0	25							43			
1	25	10,20	8,80	8,10	2,10	33,0	162	43			
5	25	10,15	8,80	7,85	2,30	32,8	157	43			
10	25	10,15	8,80	7,65	2,50	33,2	126	43			
15	27	10,20	8,85	7,40	2,80	33,3	75*	43			
20	27	10,15	8,75	6,80	3,35	33,7	116*	43			
25	34	10,10	8,70	6,40	3,70	32,9	161	43			
28									28	30	1,30
29	31	9,90	8,50	7,50	2,40	33,3	275	43			
35	34	10,00	8,60	6,95	3,05	33,0	243	43			
40	25,0	10,05	8,65	6,65	3,40	33,0	210	43			
45	25,5	10,10	8,70	6,40	3,70	32,9	203	43			
50	25,8	10,20	8,75	6,20	4,00	32,4	158	43			
55	26,4	10,20	8,75	6,00	4,20	32,6	135	43			
60	27,0	10,20	8,8	5,85	4,35	32,5	110	43			
** 65	27,2	10,20	8,8	5,75	4,45	32,6	150	43			

* = Valve Adjustment to maintain flow

** = Installation stopped because no second flush

Temp check done with hand held device, not PLC when there is 1/10 place

2-7-2009 (D2)	Temp (°C)		Pressures (Bar)				Flows			Flush		
Time (min)	Hand Held	PLC	Feed	Recirc	Perm	Feed-Perm	Recirc (m^3/hr)	Perm (L/hr)	Conc (L/hr)	Freq. (min)	Dur. (sec)	ΔP Gain
0	22,1		10,00	8,60	7,15	2,85	33,3	245	43			
5	23,4		10,05	8,65	7,30	2,75	33,1	250	43			
10	24,2		10,10	8,70	7,05	3,05	33,1	234	43			
15	24,9		10,10	8,70	6,80	3,30	33,0	191	43			
20	25,6		10,15	8,75	6,60	3,55	32,9	178	43			
25	26,1	30	10,15	8,75	6,40	3,75	32,3	152	43			
26							12,1			26	60	1,45
28	22,4	26	10,00	8,60	7,70	2,30	32,9	210	43			
30	22,3	25	9,95	8,55	7,50	2,45	32,6	259	43			
35	22,3	25	10,00	8,60	7,15	2,85	32,6	225	43			
40	24,4	26	10,05	8,65	6,90	3,15	32,5	220	43			
45	25,0	26	10,10	8,75	6,70	3,40	32,9	181	43			
50	25,7	28	10,15	8,75	6,50	3,65	32,2	165	43			
55	26,3	29	10,20	8,75	6,30	3,90	32,2	144	43			
60	26,8	29	10,20	8,80	6,20	4,00	32,1	155	43			
65	27,2	29	10,20	8,85	6,10	4,10	33,0	122	43			
70	27,6	30	10,25	8,85	6,00	4,25	32,7	105	43			

NF Installation data gathered to determine feasible flush frequency and duration WITH multiple flushes

3-7-2009 (D3)	Temp (°C)		Pressures (Bar)				Flows			Flush		
Time (min)	Hand Held	PLC	Feed	Recirc	Perm	ΔP =Feed-Perm	Recirc (m^3/hr)	Perm (L/hr)	Conc (L/hr)	Freq. (min)	Dur. (sec)	ΔP Gain
0	23,6	28	10,00	8,60	7,90	2,10	33,4	215	43			
5	24	28	10,00	8,60	7,60	2,40	33,7	175	43			
10	24,9	29	10,00	8,60	7,30	2,70	33,8	205	43			
15	25,6	30	10,05	8,65	7,10	2,95	32,9	180	43			
20	26,5	30	10,10	8,70	6,85	3,25	32,8	151	43			
25	27,1	31	10,10	8,70	6,70	3,40	32,9	137	43			
26										26	30	1,00
28	24,9	30	10,00	8,60	7,60	2,40	34,1	200	43			
30	25	29	9,95	8,55	7,55	2,40	33,2	202	43			
35	25,9	32	10,00	8,60	7,20	2,80	32,7	185	43			
40	26,6	30	10,10	8,65	7,05	3,05	32,8	165	43			
45	27,3	29	10,10	8,70	6,85	3,25	32,8	138	43			
50	27,8	30	10,10	8,75	6,75	3,35	32,9	143	43			
52										26	30	1,15
54	24,8	29	9,95	8,55	7,75	2,20	33,3	225	43			
60	25,3	28	10,00	8,6	7,35	2,65	33,3	182	43			
65	26,1	29	10	8,6	7,15	2,85	32,8	171	43			
70	26,8	31	10,10	8,70	6,95	3,15	32,7	170	43			
75	27,3	30	10,15	8,75	6,80	3,35	32,7	163	43			
80	27,8	30	10,15	8,75	6,65	3,50	33,0	105	43			
83										31	30	1,30
85	24,7	28	9,95	8,55	7,75	2,20	33,3	220	43			
90	25,2	28	10,00	8,60	7,40	2,60	32,8	210	43			
95	26,0	28	10,00	8,60	7,15	2,85	32,9	185	43			
100	26,7	29	10,05	8,65	6,95	3,10	32,8	178	43			
105	27,4	29	10,10	8,70	6,75	3,35	32,9	159	43			
110	28,0	30	10,10	8,70	6,60	3,50	32,9	151	43			

3-7-2009 (D3 Cont.)	Temp (°C)		Pressures (Bar)				Flows			Flush		
Time (min)	Hand Held	PLC	Feed	Recirc	Perm	ΔP =Feed-Perm	Recirc (m^3/hr)	Perm (L/hr)	Conc (L/hr)	Freq. (min)	Dur. (sec)	ΔP Gain
115	28,3	31	10,15	8,75	6,50	3,65	33,0	130	43			
120	28,9	31	10,20	8,80	6,35	3,85	32,6	80	43			
125	29,2	32	10,20	8,80	6,25	3,95	33,0	80	43			
130	29,5	32	10,20	8,80	6,20	4,00	33,0	75	43			
131										48	30	1,75
132	24,8	31	9,90	8,55	7,65	2,25	33,0	219	43			

6-7-2009 (D4)	Temp (°C)		Pressures (Bar)				Flows			Flush		
Time (min)	Hand Held	PLC	Feed	Recirc	Perm	ΔP =Feed-Perm	Recirc (m^3/hr)	Perm (L/hr)	Conc (L/hr)	Freq. (min)	Dur. (sec)	ΔP Gain
0	22,6	23	10,05	8,65	7,60	2,45	34,1	210	43			
5	23,3	24	10,05	8,70	7,35	2,70	33,6	204	43			
10	24,2	25	10,10	8,70	7,15	2,95	33,5	177	43			
15	25,1	25	10,15	8,75	6,95	3,20	33,7	145	43			
20	25,7	26	10,15	8,75	6,75	3,40	33,4	134	43			
30	26,8	27	10,20	8,80	6,50	3,70	32,6	107	43			
35	27,5	28	10,20	8,80	6,40	3,80	33,1	101	43			
40	28,0	28	10,25	8,85	6,30	3,95	33,0	60	43			
45		29	10,25	8,85	6,20	4,05	33,1	115	43			
46										46	30	1,75
48		27	10,00	8,55	7,70	2,30	33,3	215	43			
55		27	10,05	8,65	7,30	2,75	33,0	172	43			
60		27	10,10	8,70	7,05	3,05	33,0	180	43			
65		27	10,15	8,75	6,85	3,30	33,1	175	43			
70		28	10,15	8,75	6,70	3,45	32,8	161	43			
75		28	10,20	8,80	6,55	3,65	33,1	118	43			
80		29	10,20	8,80	6,45	3,75	33,0	96	43			
85		29	10,20	8,80	6,35	3,85	33,3	118	43			

D4 Cont.			Pressures (Bar)				Flows			Flush		
Time (min)	Abs. Time	Temp	Feed	Recirc	Perm	ΔP =Feed-Perm	Recirc (m^3/hr)	Perm (L/hr)	Conc (L/hr)	Freq. (min)	Dur. (sec)	ΔP Gain
90		29	10,20	8,80	6,20	4,00	33,2	119	43			
95		30	10,20	8,80	6,15	4,05	33,2	115	43			
105		30	10,25	8,85	6,05	4,20	33,0	102	43			
110		30	10,25	8,85	6,00	4,25	33,2	108	43			
112										66	30	1,85
114		28	10,05	8,65	7,65	2,40	32,6	223	43			
125		28	10,05	8,65	6,95	3,10	32,8	202	43			
130		28	10,10	8,70	6,70	3,40	33,0	185	43			
135		26	9,90	8,50	7,65	2,25	33,2	235	43			
140		26	9,90	8,50	7,45	2,45	33,1	233	43			
145		27	10,00	8,60	7,15	2,85	32,4	253	43			
150		27	10,00	8,60	6,95	3,05	32,8	210	43			
160		28	10,10	8,70	6,55	3,55	33,0	198	43			
170		29	10,10	8,70	6,30	3,80	33,0	175	43			
175		29	10,15	8,75	6,15	4,00	33,0	155	43			
180		30	10,15	8,75	6,10	4,05	33,4	150	43			
185		30	10,20	8,75	6,00	4,20	33,1	152	43			
190		31	10,15	8,75	5,90	4,25	32,8	138	43			
191										60	30	1,35
192		29	10,00	8,60	7,10	2,90	33,2	196	43			
195		29	10,00	8,60	6,90	3,10	33,0	199	43			
200		29	10,05	8,65	6,75	3,30	32,8	210	43			

D4 Cont.			Pressures (Bar)				Flows			Flush		
Time (min)	Abs. Time	Temp	Feed	Recirc	Perm	ΔP =Feed-Perm	Recirc (m^3/hr)	Perm (L/hr)	Conc (L/hr)	Freq. (min)	Dur. (sec)	ΔP Gain
0	200	26	9,90	8,45	8,00	1,90	32,9	231	43			
10	210	26	10,00	8,60	7,15	2,85	33,2	225	43			
20	220	27	10,05	8,65	6,80	3,25	33,1	181	43			
30	230	29	10,10	8,70	6,45	3,65	33,3	139	43			
40	240	30	10,15	8,75	6,15	4,00	33,0	153	43			
50	250	30	10,20	8,80	6,05	4,15	32,8	135	43			
55	255									55	30	1,60
60	260	27	9,95	8,55	7,40	2,55	33,1	235	43			
75	275	28	10,10	8,65	6,60	3,50	32,8	185	43			
90	290	31	10,15	8,75	6,20	3,95	32,9	163	43			
105	305	31	10,20	8,75	6,00	4,20	33,2	157	43			
110	310	32	10,20	8,80	5,90	4,30	33,3	142	43			
115	315									60	30	1,75
120	320	28	9,95	8,55	7,40	2,55	33,0	220	43			
135	335	30	10,05	8,65	6,60	3,45	33,0	171	43			
150	350	30	10,10	8,60	6,20	3,90	32,9	143	43			
165	365	31	10,15	8,75	5,95	4,20	33,2	152	43			

NF Installation Pressure Drops After 180 hours of operation

			Pressures (Bar)				Flows			Flush		
Date	Time (min)	Temp	Feed	Recirc	Perm	ΔP =Feed-Perm	Recirc (m^3/hr)	Perm (L/hr)	Conc (L/hr)	Freq. (min)	Dur. (sec)	ΔP Gain
17-7-2009	8:40	30	10,10	8,70	6,55	3,55	30,1	148	43			
rel. time	10:45	30	10,10	8,70	6,45	3,65	30,1	158	43			
0	13:50	32	10,15	8,75	6,3	3,85	29,7	152	43			
10	14:00	32	10,15	8,75	6,2	3,95	29,9	140	43			
	14:03									60	30	1,65
15	14:05	30	9,90	8,50	7,6	2,30	29,5	205	43			
20	14:10	29	9,95	8,55	7,3	2,65	29,8	214	43			
25	14:15	29	10,00	8,60	7,15	2,85	29,8	218	43			
30	14:20	9	10,00	8,60	7	3,00	30,2	201	43			
35	14:25	30	10,05	8,65	6,9	3,15	29,9	181	43			
40	14:30	30	10,05	8,65	6,7	3,35	29,7	148	43			
45	14:35	30	10,05	8,65	6,65	3,40	29,6	175	43			
50	14:40	31	10,10	8,70	6,55	3,55	29,9	143	43			
55	14:45	31	10,10	8,70	6,5	3,60	30	137	43			
60	14:50	31	10,15	8,75	6,45	3,70	29,8	139	43			
65	14:55	32	10,15	8,75	6,4	3,75	30,1	152	43			
70	15:00	32	10,15	8,75	6,3	3,85	29,9	149	43			
	15:03									60	30	1,45
75	15:05	30	9,95	8,55	7,55	2,40	29,7	223	43			
80	15:10	29	9,95	8,55	7,2	2,75	29,9	208	43			
85	15:15	29	10,00	8,55	7,05	2,95	29,4	219	43			
90	15:20	29	10,00	8,60	6,9	3,10	30	182	43			
95	15:25	30	10,00	8,60	6,8	3,20	30	188	43			
100	15:30	30	10,05	8,65	6,7	3,35	29,6	155	43			
105	15:35	31	10,05	8,65	6,6	3,45	30	153	43			
110	15:40	31	10,10	8,65	6,5	3,60	30	168	43			
115	15:45	31	10,10	8,70	6,45	3,65	29,8	145	43			
120	15:50	32	10,10	8,70	6,35	3,75	29,9	147	43			
125	15:55	32	10,10	8,70	6,3	3,80	29,8	151	43			
130	16:00	32	10,10	8,70	6,3	3,80	29,8	155	43			

In House Analysis of NF Installation during 180 hours of trial time

Date	Sample	%UVT	Dilution	DOC (mg/L)	NO3 Reading (mg/L)	Dilution	NO3 Conc. (mg/L)	Conductivity (mS/cm)	Cond (mS/m)	Salinity (g/L as NaCl)
6-7-2009	Permeate	78,2	2	8,2	<1		<1	68,9	6890	50,9
	Feed	89,1	200	494	24,6	1	24,6	85,8	8580	66,7
	Concentrate	86,3	200	577	31,3	1	31,3	68,5	6850	50,6
7-7-2009	Permeate	86,5	2	5,7	0,26		<1	55,2	5520	39,0
	Feed	89,1	200	494	4,47	5	22,4	87,9	8790	68,8
	Concentrate	93,4	500	919	6,28	5	31,4	66,7	6670	48,9
8-7-2009	Permeate	82	2	7,03	0,104		<1	61,8	6180	44,7
	Feed	88,8	200	503	4,14	5	20,7	85,5	8550	66,4
	Concentrate	93,6	500	904	5,32	5	26,6	68,8	6880	50,8
9-7-2009	Permeate	80,7	2	7,42	2,44	1	2,44	71,2	7120	53,0
	Feed	89	200	497	5,02	5	25,1	90,6	9060	71,4
	Concentrate	93,8	500	889	5,89	5	29,45	72,8	7280	54,4
13-7-2009	Permeate	84,5	2	6,30	0,143		<1	52,5	5250	36,8
	Feed	90	200	468	1,52	10	15,2	75,4	7540	56,8
	Concentrate	93,8	500	889	2,31	10	23,1	66,5	6650	48,8
14-7-2009	Permeate	83,4	2	6,62	-0,03		<1	61,2	6120	44,1
	Feed	88,5	200	512	1,79	10	17,9	85,6	8560	66,5
	Concentrate	94,5	500	838	3	10	30	70	7000	51,9
15-7-2009	Permeate	86,2	2	5,80	0,039		<1	61,1	6110	44,1
	Feed	89,9	200	471	2,08	10	20,8	84,8	8480	65,7
	Concentrate	94,7	500	823	2,97	10	29,7	68,5	6850	50,6
16-7-2009	Permeate	86,9	2	5,59	-0,098		<1	60,7	6070	43,7
	Feed	91,4	200	426	1,89	10	18,9	86,9	8690	67,8
	Concentrate	95,5	500	764	2,11	10	21,1	68,6	6860	50,6
17-7-2009	Permeate	85,3	2	6,06	0,415		<1	62,1	6210	44,9
	Feed	90,3	200	459	1,9	10	19	88,6	8860	69,5
	Concentrate	89,3	250	610	2,43	10	24,3	70,4	7040	52,3

NOM Scans performed by HWL on during NF Trials on 8-7-2009

	Partitioning of Organic Carbon (OC)						Chromatographic Fractionation of Organic Carbon (CDOC)								
8-7-2009			Approx. Molecular Weights in g/mol:			>>20.000		~1000 (see separate HS-Diagram)				300-500	<350	<350
	TOC=DOC+POC DOC=CDOC+HOC													
	Note: POC, hence TOC may be too low					Bio-		Humic				Building	Neutrals	Acids
	TOC	DOC	POC	HOC	CDOC	Polymers	DON	Subst.	DON	Aromaticity	Mol-Weight	Blocks		
	total OC	dissolved	particul.	hydrophob.	hydrophil.		(Norg)	(HS)	(Norg)	(SUVA-HS)	(Mn)			
	ppb-C	ppb-C	ppb-C	ppb-C	ppb-C	ppb-C	ppb-N	ppb-C	ppb-N	L/(mg*m)	g/mol	ppb-C	ppb-C	ppb-C
	% TOC	% TOC	% TOC	% TOC	% TOC	% TOC		% TOC		–	–	% TOC	% TOC	% TOC
Feed	644624	600925	43699	-6971	607896	4671	1831	292724	21836	3,48	607	100832	23688	185982
	100	93,2	6,8	-1,1	94,3	0,7		45,4		–	–	15,6	3,7	28,9
Permeate	182197	165202	16994	14491	150711	376	704	5547	668	2,20	599	5098	1324	138367
	100	90,7	9,3	8,0	82,7	0,2		3,0		–	–	2,8	0,7	75,9
Concentrate	721387	677457	43931	-3780	681237	7723	1894	386565	29027	3,48	604	121630	28023	137297
	100	93,9	6,1	-0,5	94,4	1,1		53,6		–	–	16,9	3,9	19,0

NOM Scans performed by HWL on during NF Trials on 15-7-2009

15-7-2009	*Approx. Molecular Weights in g/mol:*						*>>20.000*		*~1000 (see separate HS-Diagram)*				*300-500*	*<350*	*<350*
	TOC=DOC+POC DOC=CDOC+HOC														
	Note: POC. hence TOC may be too low						**Bio-**		**Humic**				**Building**	**Neutrals**	**Acids**
	TOC	**DOC**	**POC**	**HOC**	**CDOC**		**Polymers**	DON	**Subst.**	DON	*Aromaticity*	*Mol-Weight (Mn)*	**Blocks**		
	total OC	*dissolved*	*particul.*	*hydrophob.*	*hydrophil.*			*(Norg)*	**(HS)**	*(Norg)*	*(SUVA-HS)*				
	ppb-C	*ppb-C*	*ppb-C*	*ppb-C*	*ppb-C*		*ppb-C*	*ppb-N*	*ppb-C*	*ppb-N*	*L/(mg*m)*	*g/mol*	*ppb-C*	*ppb-C*	*ppb-C*
	% TOC	% TOC	% TOC	% TOC	% TOC		% TOC		% TOC		–	–	% TOC	% TOC	% TOC
Feed	**685780**	**645780**	**40000**	**110809**	**534971**		**9237**	209	**246826**	18879	**3,68**	**617**	**79711**	**1838**	**197359**
	100	94,2	5,8	16,2	78,0		1,3		36,0		–	–	11,6	0,3	28,8
Permeate	**197110**	**155260**	**41850**	**9318**	**145942**		**2127**	432	**n.n.**	n.n.	**--**	**n.n.**	**5821**	**2601**	**135393**
	100	78,8	21,2	4,7	74,0		1,1		–		–	–	3,0	1,3	68,7
Concentrate	**695954**	**665896**	**30058**	**-590**	**666486**		**6081**	1850	**363283**	29406	**3,78**	**627**	**125283**	**19179**	**152659**
	100	95,7	4,3	-0,1	95,8		0,9		52,2		–	–	18,0	2,8	21,9
DNF1 EFF	**569249**	**535029**	**34220**	**2543**	**532486**		**3780**	1855	**220765**	18160	**3,72**	**626**	**84832**	**18647**	**204461**
402251	100	94,0	6,0	0,4	93,5		0,7		38,8		–	–	14,9	3,3	35,9
DNF1 INF	**615029**	**592370**	**22659**	**23017**	**569353**		**3237**	1360	**226636**	17985	**3,63**	**614**	**83191**	**13491**	**242798**
402249	100	96,3	3,7	3,7	92,6		0,5		36,8		–	–	13,5	2,2	39,5
DNF1 VO	**309595**	**307746**	**1850**	**4023**	**303723**		**3179**	1471	**221923**	18568	**3,67**	**616**	**51665**	**26971**	**-16**
402247	100	99,4	0,6	1,3	98,1		1,0		71,7		–	–	16,7	8,7	0,0
DNF2 INF	**603468**	**589595**	**13873**	**18497**	**571098**		**3376**	1126	**232363**	18364	**3,67**	**610**	**82890**	**15723**	**236747**
402250	100	97,7	2,3	3,1	94,6		0,6		38,5		–	–	13,7	2,6	39,2
DNF2 VO	**309595**	**304971**	**4624**	**647**	**304324**		**4081**	805	**218640**	17470	**3,76**	**622**	**55838**	**25757**	**7**
402248	100	98,5	1,5	0,2	98,3		1,3		70,6		–	–	18,0	8,3	0,0

Raw data from HWL of Feed Water during NF Trials for 180 hours of operation

Date	Component	Measure	Measured	Result	Component	Average	St Dev
6-7-2009	Barium	µg/l Ba	17,8623	17,9			
8-7-2009	Barium	µg/l Ba	18,6768	18,7			
13-7-2009	Barium	µg/l Ba	21,5994	21,6			
15-7-2009	Barium	µg/l Ba	25,8674	25,9			
17-7-2009	Barium	µg/l Ba	25,7185	25,7	Barium µg/l	22,0	3,8
6-7-2009	Calcium	mg/l Ca	12,802	12,8			
8-7-2009	Calcium	mg/l Ca	14,372	14,4			
13-7-2009	Calcium	mg/l Ca	16,572	16,6			
15-7-2009	Calcium	mg/l Ca	14,333	14,3			
16-7-2009	Calcium	mg/l Ca	13,378	13,4			
17-7-2009	Calcium	mg/l Ca	15,148	15,1	Calcium mg/L	14,4	1,3
6-7-2009	Chloride	mg/l Cl	38785,6	39000			
7-7-2009	Chloride	mg/l Cl	40295	40500			
8-7-2009	Chloride	mg/l Cl	36211,5	36000			
9-7-2009	Chloride	mg/l Cl	40387,2	40500			
13-7-2009	Chloride	mg/l Cl	31169,7	31000			
14-7-2009	Chloride	mg/l Cl	34409,7	34500			
15-7-2009	Chloride	mg/l Cl	36466,6	36500			
16-7-2009	Chloride	mg/l Cl	36740	36500			
17-7-2009	Chloride	mg/l Cl	40700	40500	Chloride mg/L	37222	3241
6-7-2009	Natrium	mg/l Na	26600	26600			
7-7-2009	Natrium	mg/l Na	27979	28000			
8-7-2009	Natrium	mg/l Na	27675	27700			
9-7-2009	Natrium	mg/l Na	27959	28000			
13-7-2009	Natrium	mg/l Na	23729	23700			
14-7-2009	Natrium	mg/l Na	24598	24600			
15-7-2009	Natrium	mg/l Na	26292	26300			
16-7-2009	Natrium	mg/l Na	17183	17200			
17-7-2009	Natrium	mg/l Na	27542	27500	Natrium mg/L	25511	3466
6-7-2009	Nitraat	mg/l N	0,005	<0.03			
6-7-2009	Nitraat	mg/l NO3	0,0221	<0.14			
7-7-2009	Nitraat	mg/l N	-0,012	<0.03			
7-7-2009	Nitraat	mg/l NO3	-0,0531	<0.14			
8-7-2009	Nitraat	mg/l N	0,57	0,57			
8-7-2009	Nitraat	mg/l NO3	2,5234	2,52			
9-7-2009	Nitraat	mg/l N	3,218	3,22			
9-7-2009	Nitraat	mg/l NO3	14,2461	14,2			
13-7-2009	Nitraat	mg/l N	0,008	<0.03			
13-7-2009	Nitraat	mg/l NO3	0,0354	<0.14			
14-7-2009	Nitraat	mg/l N	3,081	3,08			
14-7-2009	Nitraat	mg/l NO3	13,6396	13,6			
15-7-2009	Nitraat	mg/l N	1,892	1,89			
15-7-2009	Nitraat	mg/l NO3	8,3759	8,38			
16-7-2009	Nitraat	mg/l N	0,042	0,04			
16-7-2009	Nitraat	mg/l NO3	0,1859	0,19			
17-7-2009	Nitraat	mg/l N	0,009	<0.03			

Raw data from HWL of Feed Water during NF Trials for 180 hours of operation (continued)							
17-7-2009	Nitraat	mg/l NO3	0,0398	<0.14	Nitraat mg/l	7,78	6,34
6-7-2009	DOC	mg/l C	684,9	685			
7-7-2009	DOC	mg/l C	682,6	683			
8-7-2009	DOC	mg/l C	611,8	612			
9-7-2009	DOC	mg/l C	686,6	687			
13-7-2009	DOC	mg/l C	602,9	603			
14-7-2009	DOC	mg/l C	694,6	695			
15-7-2009	DOC	mg/l C	636,8	637			
16-7-2009	DOC	mg/l C	586,4	586			
17-7-2009	DOC	mg/l C	567,4	567	DOC mg/L	639	49
6-7-2009	Sulfaat	mg/l SO4	6970,4	6970			
8-7-2009	Sulfaat	mg/l SO4	7559,7	7560			
13-7-2009	Sulfaat	mg/l SO4	6232,5	6230			
15-7-2009	Sulfaat	mg/l SO4	6114,9	6110			
17-7-2009	Sulfaat	mg/l SO4	5530	5530	Sulfate mg/l SO4	6480	792
6-7-2009	Totaal fosfaat	mg/l P	2,04	2			
6-7-2009	Totaal fosfaat	mg/l PO4	6,25464	6			
8-7-2009	Totaal fosfaat	mg/l P	2,302	2			
8-7-2009	Totaal fosfaat	mg/l PO4	7,05793	7			
13-7-2009	Totaal fosfaat	mg/l PO4	13,1225	10			
13-7-2009	Totaal fosfaat	mg/l P	4,28	4			
15-7-2009	Totaal fosfaat	mg/l P	1,308	1			
15-7-2009	Totaal fosfaat	mg/l PO4	4,01033	4			
17-7-2009	Totaal fosfaat	mg/l PO4	3,67613	4			
17-7-2009	Totaal fosfaat	mg/l P	1,199	1	Phosphate mg/l PO4	6	2

Raw data from HWL of Permeate Water during NF Trials for 180 hours of operation

Date	Component	Measured	Measurement	Result	Component	Average	St Dev
6-7-2009	Barium	µg/l Ba	11,8022	11,8			
8-7-2009	Barium	µg/l Ba	10,7177	10,7			
13-7-2009	Barium	µg/l Ba	13,5173	13,5			
15-7-2009	Barium	µg/l Ba	18,5736	18,6			
17-7-2009	Barium	µg/l Ba	19,3675	19,4	Barium µg/l	14,8	4,0
6-7-2009	Calcium	mg/l Ca	13,539	13,5			
8-7-2009	Calcium	mg/l Ca	12,793	12,8			
13-7-2009	Calcium	mg/l Ca	14,574	14,6			
15-7-2009	Calcium	mg/l Ca	12,682	12,7			
17-7-2009	Calcium	mg/l Ca	14,923	14,9	Calcium mg/L	13,7	1,0
6-7-2009	Chloride	mg/l Cl	22002,6	22000			
7-7-2009	Chloride	mg/l Cl	23892,2	24000			
8-7-2009	Chloride	mg/l Cl	25893,3	26000			
9-7-2009	Chloride	mg/l Cl	33876	34000			
13-7-2009	Chloride	mg/l Cl	22428,4	22500			
14-7-2009	Chloride	mg/l Cl	28733,1	28500			
15-7-2009	Chloride	mg/l Cl	27601,9	27500			
16-7-2009	Chloride	mg/l Cl	26480	26500			
17-7-2009	Chloride	mg/l Cl	29400	29500	Chloride mg/L	26722	3751
6-7-2009	Natrium	mg/l Na	14845	14800			
7-7-2009	Natrium	mg/l Na	15388	15400			
8-7-2009	Natrium	mg/l Na	18122	18100			
9-7-2009	Natrium	mg/l Na	21377	21400			
13-7-2009	Natrium	mg/l Na	14788	14800			
14-7-2009	Natrium	mg/l Na	16410	16400			
15-7-2009	Natrium	mg/l Na	17663	17700			
16-7-2009	Natrium	mg/l Na	26532	26500			
17-7-2009	Natrium	mg/l Na	18291	18300	Natrium mg/L	18156	3768
6-7-2009	Nitraat	mg/l N	0,386	0,39			
6-7-2009	Nitraat	mg/l NO3	1,7088	1,71			
7-7-2009	Nitraat	mg/l N	0,269	0,27			
7-7-2009	Nitraat	mg/l NO3	1,1909	1,19			
8-7-2009	Nitraat	mg/l N	0,114	0,11			
8-7-2009	Nitraat	mg/l NO3	0,5047	0,5			
9-7-2009	Nitraat	mg/l N	1,27	1,27			
9-7-2009	Nitraat	mg/l NO3	5,6223	5,62			
13-7-2009	Nitraat	mg/l N	0,002	<0.03			
13-7-2009	Nitraat	mg/l NO3	0,0089	<0.14			
14-7-2009	Nitraat	mg/l N	0,209	0,21			
14-7-2009	Nitraat	mg/l NO3	0,9252	0,93			
15-7-2009	Nitraat	mg/l N	-0,011	<0.03			
15-7-2009	Nitraat	mg/l NO3	-0,0487	<0.14			
16-7-2009	Nitraat	mg/l N	1,27	1,27			
16-7-2009	Nitraat	mg/l NO3	5,6223	5,62			

Raw data from HWL of Permeate Water during NF Trials for 180 hours of operation (continued)							
17-7-2009	Nitraat	mg/l N	0,032	0,03			
17-7-2009	Nitraat	mg/l N	0,032	0,03			
17-7-2009	Nitraat	mg/l NO3	0,1417	0,14	Nitraat mg/l NO3	2,24	2,36
6-7-2009	DOC	mg/l C	663,2	663			
7-7-2009	DOC	mg/l C	175,7	176			
8-7-2009	DOC	mg/l C	154,5	154			
9-7-2009	DOC	mg/l C	224,5	224			
13-7-2009	DOC	mg/l C	178,5	178			
14-7-2009	DOC	mg/l C	205,6	206			
15-7-2009	DOC	mg/l C	177,7	178			
16-7-2009	DOC	mg/l C	152,6	153			
17-7-2009	DOC	mg/l C	145,3	145	DOC mg/L	177	27
6-7-2009	Sulfaat	mg/l SO4	243,02	243			
8-7-2009	Sulfaat	mg/l SO4	555,55	556			
13-7-2009	Sulfaat	mg/l SO4	16,772	16,8			
15-7-2009	Sulfaat	mg/l SO4	358,89	359			
17-7-2009	Sulfaat	mg/l SO4	364,57	365	Sulfate mg/l SO4	308	198
6-7-2009	Totaal fosfaat	mg/l P	0,239	0,2			
6-7-2009	Totaal fosfaat	mg/l PO4	0,732774	0,7			
8-7-2009	Totaal fosfaat	mg/l PO4	1,01485	1			
8-7-2009	Totaal fosfaat	mg/l P	0,331	0,3			
13-7-2009	Totaal fosfaat	mg/l PO4	0,6132	0,6			
13-7-2009	Totaal fosfaat	mg/l P	0,2	0,2			
15-7-2009	Totaal fosfaat	mg/l P	0,168	0,2			
15-7-2009	Totaal fosfaat	mg/l PO4	0,515088	0,5			
17-7-2009	Totaal fosfaat	mg/l PO4	0,585606	0,6			
17-7-2009	Totaal fosfaat	mg/l P	0,191	0,2	Phosphate mg/l PO4	0,7	0,2

Raw data from HWL of Concentrate Water during NF Trials for 180 hr of operation

Date	Component	Measured	Measurement	Result	Component	Average	St Dev
6-7-2009	Barium	µg/l Ba	26,2327	26,2			
8-7-2009	Barium	µg/l Ba	27,7422	27,7			
13-7-2009	Barium	µg/l Ba	27,7121	27,7			
15-7-2009	Barium	µg/l Ba	34,3936	34,4			
17-7-2009	Barium	µg/l Ba	32,9275	32,9	Barium µg/l	29,8	3,6
6-7-2009	Calcium	mg/l Ca	20,82	20,8			
8-7-2009	Calcium	mg/l Ca	22,337	22,3			
13-7-2009	Calcium	mg/l Ca	21,482	21,5			
15-7-2009	Calcium	mg/l Ca	22,027	22			
17-7-2009	Calcium	mg/l Ca	22,434	22,4	Calcium mg/L	21,8	0,7
6-7-2009	Chloride	mg/l Cl	26168,6	26000			
7-7-2009	Chloride	mg/l Cl	23006,9	23000			
8-7-2009	Chloride	mg/l Cl	26382,8	26500			
9-7-2009	Chloride	mg/l Cl	29500,3	29500			
13-7-2009	Chloride	mg/l Cl	25351,8	25500			
14-7-2009	Chloride	mg/l Cl	25950,5	26000			
15-7-2009	Chloride	mg/l Cl	25950,5	26000			
16-7-2009	Chloride	mg/l Cl	26360	26500			
17-7-2009	Chloride	mg/l Cl	34400	34500	Chloride mg/L	27056	3245
6-7-2009	Natrium	mg/l Na	21794	21800			
7-7-2009	Natrium	mg/l Na	21047	21000			
8-7-2009	Natrium	mg/l Na	22365	22400			
9-7-2009	Natrium	mg/l Na	23496	23500			
13-7-2009	Natrium	mg/l Na	21385	21400			
14-7-2009	Natrium	mg/l Na	20295	20300			
15-7-2009	Natrium	mg/l Na	21295	21300			
16-7-2009	Natrium	mg/l Na	21277	21300			
17-7-2009	Natrium	mg/l Na	21745	21700	Natrium mg/L	21633	906
6-7-2009	Nitraat	mg/l N	-0,012	<0.03			
6-7-2009	Nitraat	mg/l NO3	-0,0531	<0.14			
7-7-2009	Nitraat	mg/l N	0,001	<0.03			
7-7-2009	Nitraat	mg/l NO3	0,0044	<0.14			
8-7-2009	Nitraat	mg/l N	0,27	0,27			
8-7-2009	Nitraat	mg/l NO3	1,1953	1,2			
9-7-2009	Nitraat	mg/l N	0,148	0,15			
9-7-2009	Nitraat	mg/l NO3	0,6552	0,66			
13-7-2009	Nitraat	mg/l N	-0,003	<0.03			
13-7-2009	Nitraat	mg/l NO3	-0,0133	<0.14			
14-7-2009	Nitraat	mg/l N	0,033	0,03			
14-7-2009	Nitraat	mg/l NO3	0,1461	0,15			
15-7-2009	Nitraat	mg/l N	-0,022	<0.03			
15-7-2009	Nitraat	mg/l NO3	-0,0974	<0.14			
16-7-2009	Nitraat	mg/l N	0,017	<0.03			
16-7-2009	Nitraat	mg/l NO3	0,0753	<0.14			
17-7-2009	Nitraat	mg/l N	0,024	<0.03			
17-7-2009	Nitraat	mg/l NO3	0,1062	<0.14	Nitraat mg/l NO3	0,67	0,53

Raw data from HWL of Concentrate Water during NF Trials for 180 hr of operation (continued)

Date	Component	Measure	Measurement	Result	Component	Average	St Dev
6-7-2009	DOC	mg/l C	932,1	932			
7-7-2009	DOC	mg/l C	793,3	793			
8-7-2009	DOC	mg/l C	721,4	721			
9-7-2009	DOC	mg/l C	672,6	673			
13-7-2009	DOC	mg/l C	689,1	689			
14-7-2009	DOC	mg/l C	720,6	721			
15-7-2009	DOC	mg/l C	782,8	783			
16-7-2009	DOC	mg/l C	711,2	711			
17-7-2009	DOC	mg/l C	611,4	611	DOC mg/L	737	91
6-7-2009	Sulfaat	mg/l SO4	8723,8	8720			
8-7-2009	Sulfaat	mg/l SO4	9559,7	9560			
13-7-2009	Sulfaat	mg/l SO4	8993,1	8990			
15-7-2009	Sulfaat	mg/l SO4	9382,3	9380			
17-7-2009	Sulfaat	mg/l SO4	7908,9	7910	Sulfate mg/l SO4	8912	649
6-7-2009	Totaal fosfaat	mg/l PO4	7,09472	7			
6-7-2009	Totaal fosfaat	mg/l P	2,314	2			
8-7-2009	Totaal fosfaat	mg/l P	2,45	2			
8-7-2009	Totaal fosfaat	mg/l PO4	7,5117	8			
13-7-2009	Totaal fosfaat	mg/l PO4	4,80442	5			
13-7-2009	Totaal fosfaat	mg/l P	1,567	2			
15-7-2009	Totaal fosfaat	mg/l P	1,822	2			
15-7-2009	Totaal fosfaat	mg/l PO4	5,58625	6			
17-7-2009	Totaal fosfaat	mg/l P	1,453	1			
17-7-2009	Totaal fosfaat	mg/l PO4	4,4549	4	Phosphate mg/l PO4	6	2

APPENDIX G

CONCENTRATION HYPOTHESIS AND REVERSE OSMOSIS CALCULATIONS

Two sets of assumptions and iterations for calculating increase salt concentrations with decreased efficiencies

Assumptions and Givens	
Feed Tank Conc (g/L)	301
DW Concentration (g/L)	0,4
Total Regen Flow (L/hr)	350
Pilot Efficiency (percent)	78,5
Clean Return Flow (L/hr)	275
Suppliment Flow (L/hr)	75,3
Concentration Fraction of Salt Remaining (g/L)/(g/L)	0,463

Upper Limit Iterations			Lower Limit Iterations		
It. #	PV1 Conc (g/L)	Return Conc (g/L)	It. #	PV1 Conc (g/L)	Return Conc (g/L)
0	102,4	47,4	0	102,4	47,4
1	101,9	47,2	1	37,3	17,3
2	101,8	47,1	2	13,6	6,3
3	101,7	47,1	3	5,0	2,3
4	101,7	47,1	4	1,9	0,9
5	101,7	47,1	5	0,8	0,4
6	101,7	47,1	6	0,4	0,2
7	101,7	47,1	7	0,2	0,1
8	101,7	47,1	8	0,2	0,1

Assumptions and Givens	
Feed Tank Conc (g/L)	301
DW Concentration (g/L)	0,4
Total Regen Flow (L/hr)	350
Pilot Efficiency (percent)	70
Clean Return Flow (L/hr)	245
Suppliment Flow (L/hr)	105
Concentration Fraction of Salt Remaining (g/L)/(g/L)	0,463

Upper Limit Iterations			Lower Limit Iterations		
It. #	PV1 Conc (g/L)	Return Conc (g/L)	It. #	PV1 Conc (g/L)	Return Conc (g/L)
0	102,4	47,4	0	102,4	47,4
1	123,5	57,2	1	33,3	15,4
2	130,3	60,3	2	10,9	5,1
3	132,5	61,3	3	3,7	1,7
4	133,2	61,7	4	1,3	0,6
5	133,5	61,8	5	0,5	0,3
6	133,5	61,8	6	0,3	0,1
7	133,6	61,8	7	0,2	0,1
8	133,6	61,8	8	0,2	0,1

RO Operating Pressure Requirements

RETENTATE CONC. = 100 g/L	
Feed Conc. (Cf), mg/L	40000
Retentate Conc. (Cr), mg/L	100000
Conversion Factor (B), atm / 1000mg/L	0.000766
Average Osmotic Pressure (ΔΠ), atm ΔΠ=B*[(Cf+Cr)/2]	53.62
Water Flux Rate (Fw), gal/ft2.day	5
Water Permeability Constant (A), gal/ft2.day.atm	0.32
Operating Pressure of RO (ΔP), atm ΔP=Fw/A + ΔΠ	69.245
ΔP in psi	1018

RETENTATE CONC. = 360 g/L	
Feed Conc. (Cf), mg/L	40000
Retentate Conc. (Cr), mg/L	360000
Conversion Factor (B), atm / 1000mg/L	0.000776
Average Osmotic Pressure (ΔΠ), atm ΔΠ=B*[(Cf+Cr)/2]	155.2
Water Flux Rate (Fw), gal/ft2.day	5
Water Permeability Constant (A), gal/ft2.day.atm	0.32
Operating Pressure of RO (ΔP), atm ΔP=Fw/A + ΔΠ	170.825
ΔP in psi	2511